FITCHBURG AND LEOMINSTER WATER SUPPLY PLANNING PROJECT

SUMMARY REPORT

FINAL REPORT

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PREPARED FOR:

MASSACHUSETTS DEPARTMENT OF CONSERVATION AND RECREATION
MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION
FITCHBURG WATER DEPARTMENT
LEOMINSTER WATER DIVISION

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1.0 Introduction

The Executive Office of Environmental Affairs Watershed Initiative commissioned a study to develop long-term monitoring plans and Drought Contingency Plans for the Fitchburg and Leominster water supply systems. Both cities reside within the Nashua River Basin as shown in Figure 1.0-1 and have developed water supply systems that service customers within their cities and the surrounding area. Fitchburg's and Leominster's[1] primary water supply sources are a network of reservoirs as shown in Figures 1.0-2 and 1.0-3, respectively. Currently, neither city consistently measures reservoir water elevations, thus the storage available to meet demands is not continuously monitored. During periods of low flow or drought the cities more closely monitor reservoir water elevations, system demands, flow levels, precipitation and other parameters to determine if there could be a potential supply shortage.

In an effort to assist Fitchburg and Leominster with having continual information on their water supply capacities, a monitoring program and spreadsheet-based tracking system was developed. The purpose of the monitoring program, which entails entering daily reservoir water elevations and daily demands into custom designed spreadsheets, is to have up-to-date information on individual reservoir storage capacities and overall system storage capacities. The spreadsheet compares the available storage capacity relative to system demand (water withdrawals) on a daily basis, and also forecasts into the future if there could be a supply shortfall. Pre-determined trigger levels are established when storage capacities fall to a certain percentage of full capacity. The monitoring plan is designed to inform the water suppliers when trigger levels occur and identify different warning levels depending on the severity. When storage capacities fall to the certain trigger levels, various water conservation measures are enacted (as described in a Drought Contingency Plan) to reduce demand and conserve water. The monitoring plan was based on the Pennsylvania Department of Environmental Protection's *Drought Triggers for Public Water Suppliers using Reservoir Sources*. This study applied the same techniques and methods as suggested for Pennsylvania water supply reservoir systems.

The second component of this study is the development of Drought Contingency Plans for both cities, although as discussed later Fitchburg filed a plan with the Massachusetts Department of Environmental Protection in 2002. The Drought Contingency Plans include different levels of water conservation depending on the severity of water shortage or drought conditions.

The final products of this study are monitoring spreadsheets, Drought Contingency Plans and this brief summary report. It should be noted that the Drought Contingency Plans are a separate document. Monitoring spreadsheets are provided electronically as Excel files.

All figures appear at the end of the report.

[1] As described later, Leominster also has a groundwater withdrawal, although the annual groundwater withdrawal volumes represent only 8-10% of their water supply.

2.0 Fitchburg and Leominster Water Supply Systems

2.1 Fitchburg Water Supply System (Public Water Supplier ID No.: 2097000)

The Fitchburg Water Department has seven active reservoirs and three[2] inactive reservoirs currently not in use as shown in the schematic – Figure 2.1-1. A plan map of the system showing the active reservoir locations is shown in Figure 1.0-2. The Fitchburg system is broken into the Northern and Southern systems. All water demands are supplied by the reservoir network; Fitchburg has no groundwater withdrawals. It should be noted that the Northern and Southern distribution systems are connected only after water treatment occurs (raw water from the two systems are not mixed until after treatment).

The Northern system consists of Fitchburg Reservoir, Scott Reservoir, and Lovell Reservoir. Water is conveyed via gravity between all three reservoirs and eventually flows into the Northern Reservoirs Treatment Plant, where it is treated and fed into the water distribution system. Fitchburg Reservoir discharges to Falulah Brook and travels approximately 2.5 miles before becoming impounded at Lovell Reservoir. Roughly 500 feet below Lovell Reservoir is Falulah Reservoir, which is currently inactive. Historically, Falulah Reservoir was used for water supply needs, but in 2000 was taken out of service[3]. Scott Reservoir is located west of Falulah Brook and discharges into Scott Brook which eventually flows into Falulah Reservoir. Discharges from Falulah Reservoir flow into the Northern Reservoir Treatment Plant, where the water is treated and fed into the distribution system.

The Southern system consists of Bickford Reservoir, Mare Meadow Reservoir, Meetinghouse Reservoir and Wachusett Reservoir[4]. Water is pumped from Bickford to Mare Meadow, and then pumped from Mare Meadow to Meetinghouse. Meetinghouse Reservoir discharges to Smith Brook which feeds into the Southern Reservoir Treatment Plant where water is again treated and pumped into the distribution system. Water from Wachusett Reservoir is pumped directly into the Southern Reservoir Treatment Plant.

It should be noted that Bickford and Mare Meadow Reservoirs reside in the Chicopee River Basin, outside the Nashua River Basin. The spillway crest elevation, useable storage capacity and contributing drainage of each reservoir are shown in Table 2.1-1. In addition, shown in Figure 2.1-2 is a bar chart displaying the storage capacity of the various reservoirs in the Fitchburg system.

Table 2.1-1: Fitchburg Water Supply Reservoir Characteristics

Reservoir	Spillway Crest Elev. (NGVD msl of 1929)	**Useable Storage (million gallons, MG)	**Contributing Drainage Area (mi^2)
Northern Reservoir System			
Fitchburg Reservoir	1007 feet	685.5 MG	2.09 mi^2

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[2] The three inactive reservoirs include: Shattuck, Falulah, and Overlook Reservoirs. These reservoirs serve as emergency back-up only.

[3] It should be noted that all three inactive reservoirs (Shattuck, Falulah and Overlook) were taken out of service in 2000. They will remain inactive, but will serve as emergency back-up, if needed.

[4] Note that the Wachusett Reservoir referenced in this report is <u>not</u> the same as the Massachusetts Water Resource Authority's Wachusett Reservoir.

Scott Reservoir	883.3 feet	191.2 MG	0.73 mi^2
Lovell Reservoir	764.0 feet	360.1 MG	1.51 mi^2
TOTAL Northern Reservoir System Storage		**1236.8 MG**	
Southern Reservoir System			
Bickford Reservoir	1045.0 feet	908.2 MG	3.60 mi^2
Mare Meadow Reservoir	1060.0 feet	1733.0 MG	3.00 mi^2
Meetinghouse Reservoir	1033.0 feet	645.5 MG	1.47 mi^2
Wachusett Reservoir	892.4 feet	390.3 MG	1.52 mi^2
TOTAL Northern Reservoir System Storage		**3677.0 MG**	
TOTAL Northern and Southern Reservoir Storage		**4913.8 MG**	

* Storage capacities were provided by the USGS as part of the USGS/MDEP Firm Yield Analysis Study
** Drainage Areas obtained from Public Water Supply Annual Statistical Report

2.1.1 Fitchburg Reservoir Storage and Historical Demands

Each year water suppliers registered and permitted under the Water Management Act (WMA) are required to file a Public Water Supply Annual Statistical Report with the Massachusetts Department of Environmental Protection (MDEP). Both Fitchburg and Leominster report to the Central Region of MDEP in Worcester. Among other items, the annual reports contain information on water withdrawals from individual reservoirs on a monthly basis, total annual withdrawal, peak daily withdrawal, population served, and the percent break down of water delivered to various customers (residential, industrial, commercial, etc). Annual reports were obtained for years 1999-2002.

In March 2002, CDM completed a report entitled *Hydrologic Assessment Nashua River Watershed Report*. It should be noted that CDM's report evaluated water use from annual reports from 1994-1998. Later in this report more up-to-date water use data is provided, thus the annual water demands vary. Within the CDM report there is considerable information on the Fitchburg and Leominster water supply system as it pertains to current and future demands. Basic information from the CDM report is summarized here to provide the reader with additional background on the water supplier system.

Based on the CDM report, the breakdown of Fitchburg's water usage is as follows: residential (35%), commercial (7%), industrial (12%), other (27%) and unaccounted for water (19%). Also based on CDM's report the estimated population served in 2000 was 38,278, and the predicted population in 2020 is 37,890, a 1% decrease. The average daily demand (ADD) in 2000 was estimated at 5.95 million gallons per day (MGD), and the predicted demand in 2020 is 5.88 MGD, a slight decrease.

Figure 2.1.1-1 is a graph illustrating the annual water withdrawals for years 1999-2002, which average approximately 2,289 million gallons (MG) annually or 6.3 MGD. The graph also shows the full storage capacity of the Northern and Southern Reservoir systems and the collective total (Northern and Southern) relative to the annual withdrawal volumes. As shown in Table 2.1-1 and in Figure 2.1.1-1 the storage capacities of the Northern, Southern and Northern/Southern Reservoir systems is 1236.8 MG, 3677 MG and 4918.8 MG, respectively. Comparing annual withdrawal volumes (demand) relative to the total system storage capacity, there are approximately two years of storage capacity available to meet current demands. Thus, theoretically, without any inflow to the reservoir system there is sufficient water in storage to meet demands for roughly two years. In fact there is approximately 1.5 years of storage in the Southern system to meet demand. In summary, the Fitchburg Water Department has significant storage capacity relative to annual demand.

It should be noted that Fitchburg has two separate withdrawal allocations. One for the Nashua River Basin (Meetinghouse, Wachusett, Lovell, Scott, Fitchburg Reservoirs) for 6.19 MGD and one for the Chicopee Basin (Bickford and Mare Meadow) of 2.93 MGD.

As noted above the average daily demand over the period 1999-2002 was 6.3 MGD, however, demand varies seasonally when summer usage increases as illustrated in Figure 2.1.1-2. Peak daily demands in 1999, 2000, 2001, and 2002 were 12.2 MGD, 7.9 MGD, 7.5 MGD and 8.8 MGD, respectively.

It should be also noted that there are no minimum flow requirements below any of Fitchburg's dams.

2.2 Leominster Water Supply System (Public Water Supplier ID No. 2153000)

The Leominster Water Division has several surface water sources including Fall Brook Reservoir, the Notown Reservoir system and the Distributing Reservoir system. A schematic of the system is shown in Figure 2.2-1. A plan map showing the location of the reservoir system is shown in Figure 1.0-3. Although not evaluated as part of this study, Leominster also has the Southeast Corner wellfield, a groundwater source used to supplement their water supply demands. The wellfield provides approximately 8-10% of the overall demand, while the remaining 90-92% is provided by the reservoir system.

Based on information contained in the same CDM report referenced, the breakdown of water usage is as follows: residential (50%), commercial (24%), industrial (14%), other (3%) and unaccounted for water (9%). The CDM report noted the estimated population served in 2000 was 42,253, and the predicted population in 2020 is 49,300, a 16% increase. The average daily demand in 2000 is reported as 4.06 MGD, whereas in 2020 the ADD is predicted to be 5.20 MGD (a 28% increase).

The Notown Reservoir system consists of Notown Reservoir, Goodfellow Pond and Simonds Pond, which flow by gravity in series- Notown flows to Goodfellow and then to Simonds. A gatehouse is located at the lowermost Simonds Pond, which contains a 16-inch pipe to convey water below the dam and a 20-inch raw water transmission main which flows to Leominster's Notown Water Filtration Plant. The Notown system services the city's High Service Area.

The Distributing Reservoir system is located in west-central Leominster and consists of three reservoirs: Haynes Reservoir, Morse Reservoir and Distributing Reservoir, which flow by gravity. Haynes discharges into Haynes Brook which flows approximately 1.5 miles into Distributing Reservoir. Haynes Reservoir may also be diverted to Morse Reservoir. A diversion dam is located on Haynes Brook below Haynes Reservoir and when activated can divert water into Morse Reservoir via gravity. Morse Reservoir overflows into a brook which drains into

Haynes Brook and then to Distributing Reservoir. At the Distributing Reservoir there are two 14-inch pipes from which water is withdrawn into Leominster's Low Service Area.

Lastly, the Fallbrook Reservoir which supplies water to the Intermediate Service Area is located in southern Leominster. Basic information on each reservoir in the Leominster water supply system is shown in Table 2.2-1. In addition, shown in Figure 2.2-2 is a bar chart displaying the storage capacity of the various reservoirs in the Leominster system.

Table 2.2-1: Leominster Water Supply Reservoir Characteristics

Reservoir	Spillway Crest Elev. (NGVD msl of 1929)	*Useable Storage (million gallons, MG)	**Contributing Drainage Area (mi^2)
Notown	733.8 feet	709.5 MG	4.53 mi^2
Goodfellow Pond	713.3 feet	9.2 MG	0.41 mi^2
Simonds Pond	690.1 feet	16.8 MG	0.23 mi^2
Haynes Reservoir	839.6 feet	130.8 MG	0.42 mi^2
Morse Reservoir	672.8 feet	45.5 MG	0.64 mi^2
Distributing Reservoir	579.0 feet	7.1 MG	0.83 mi^2
Fallbrook Reservoir	651.5 feet	352.2 MG	1.42 mi^2
Note: The City of Leominster has employed its own vertical datum in the past, which is 1.62 feet higher than the 1929 datum listed in Table 2.2-1.			

* Storage capacities were provided by the USGS as part of the USGS/MDEP Firm Yield Analysis Study
** Drainage Areas obtained from Public Water Supply Annual Statistical Report

2.2.1 Leominster Reservoir Storage and Historical Demands

As noted above Annual Public Water Supply Statistical Reports for years 1998-2002 were obtained from the MDEP and used in this analysis. Figure 2.2.1-1 depicts the annual water withdrawals for years 1999-2002, which have averaged approximately 1,592 MG or 4.4 MGD. The graph also shows the storage capacity of the Leominster reservoir system (1271.7 MG) relative to annual withdrawal volumes. Comparing annual demands relative to storage capacities, there are approximately 0.8 years of storage capacity available to meet current demands.

Similar to Fitchburg, the summer demand increases as shown in Figure 2.2.1-2. Peak daily demands in 1999, 2000, 2001, and 2002 were 7.7 MGD, 5.9 MGD, 7.3 MGD and 6.8 MGD, respectively.

There are no minimum flow requirements below any of Leominster's dams.

3.0 United States Geological Survey- Past Studies

3.1 Reservoir Storage Curves

The United States Geological Survey (USGS) is in the process of conducting a Firm Yield Analysis for numerous surface water reservoir systems in the Commonwealth, including those operated by Fitchburg and Leominster. As part of the firm yield study, in the summer of 2002 the USGS collected bathymetric data of each reservoir in the Fitchburg water system. Similarly bathymetric maps of the Leominster reservoirs were obtained from a separate study. In the summer of 2000, Ocean Surveys conducted bathymetric surveys of the Leominster impoundments. The end result of both bathymetric surveys was the development of stage (reservoir elevation) versus storage (in million gallons, MG) curves for each reservoir in the Leominster and Fitchburg systems. Included in Appendix A are graphical displays of the reservoir storage curves, along with the spillway crest elevation and intake elevation. The useable storage capacity of each reservoir was computed based on the volume of water between the intake elevation and the spillway crest elevation. Storage below the intake is considered dead storage: unavailable for water supply.

Using the various stage versus storage points for each reservoir, the USGS developed "best-fit" curves. Each stage versus storage curve has an equation, which was used later in the spreadsheet analysis such that for a given reservoir elevation the corresponding storage can be readily computed.

3.2 Reservoir Inflow Data

Another component of the USGS Firm Yield study was to estimate net inflows to each of the Fitchburg and Leominster Reservoirs. A methodology, referred to as the QPPQ transform developed by Fennessey (1994), was applied to estimate the net inflow into each of the reservoirs. It is not the intent of this report to review the intricate details of the QPPQ transform or how it was applied to estimate reservoir net inflows; only basic information is provided herein.

Ideally reservoir inflows would be gauged; however, as is commonly the case no gauges are available to measure inflow to any of the reservoirs. As such, stream gauge data was transformed from a USGS gauged stream to estimate inflow at each reservoir. Fennessey (1994) developed a procedure which provides an estimate of the daily streamflows at an ungauged location. The first step in the process is to identify a nearby stream that is relatively unimpacted by human activities such as diversions, impoundments, withdrawals, etc. In this case, the USGS selected the Squannacook River near West Groton, MA[5] as the surrogate gauge. The USGS developed an annual period of record flow duration curve for the Squannacook River which represents the relationship between streamflow and the percent of time a given flow is equaled or exceeded.

The QPPQ transform requires other input parameters, which, when combined with the flow duration analysis for the Squannacook River, predicts reservoir net inflows. The other input parameters include:

- Climate (Average Annual Precipitation and Average Annual Snowfall),
- Basin Characteristics (Basin Area, Mean Channel Slope, Average Watershed Elevation),
- Soil (Maximum Soil Retention- requires the computation of the basin curve number)

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[5] Squannacook River, USGS Gage No. 01096000, Drainage Area = 63.7 mi^2, excludes 2.16 mi^2 above outlet of Ashby Reservoir.

Fennessey developed a series of equations that incorporate the above input parameters and the exceedence flows (from the Squannacook River) to estimate the average daily net inflow to each reservoir. Note that the net inflow accounts for direct precipitation and impoundment evaporation. In the end, the USGS developed separate equations for each individual reservoir in the Fitchburg and Leominster system to estimate the net inflow. These "hard-coded" equations require only the Squannacook River flow to then estimate the reservoir net inflows.

It should be noted that the USGS reports the Squannacook River flow in "real-time" meaning that flows can be readily downloaded from the USGS website[6] and entered into the monitoring spreadsheet (the reported flows are instantaneous). The monitoring spreadsheet uses the real time flow data, and through the "hard-coded" equations within the spreadsheet the net inflow to reservoir is estimated.

4.0 Monitoring Plan/Spreadsheet Application

One of primary components of this study is to develop monitoring plans such that Fitchburg and Leominster have better insight into their available storage capacities and can predict potential shortages. The monitoring plan requires the water suppliers to enter the following data on a daily basis into an Excel spreadsheet [Note: the spreadsheet is not really a monitoring plan]::

- reservoir water elevation in feet (datum based on NGVD, 1929) for each reservoir in the system;
- the average daily demand (commonly called the depletion rate) for the entire system in MGD. If no demand is entered the spreadsheet defers to the average monthly demand (in MGD) based on the 1999-2002 data; and
- as an option, users can enter the real-time flow recorded at the USGS gage on the Squannacook River near West Groton, MA (more on this later).

Currently USGS style staff gages are not installed at each of the reservoirs to measure water elevations, a key input to the monitoring plan. However, in July 2004, USGS style staff gages were obtained and provided to both Fitchburg and Leominster for installation. Fitchburg and Leominster are volunteering their survey crews to install the gages relative to the NGVD 1929 datum (setting to the correct datum is critical since the reservoir elevation versus storage curves are based on the NGVD 1929 datum).

In terms of the monitoring spreadsheet once the reservoir elevation and demand are entered, the spreadsheet computes the following:

- The available storage (based on the stage versus storage curve) is computed for each individual reservoir and for each water supplier's entire reservoir network. In addition, the percent of available storage relative to full capacity is computed. These data are presented both in tabular and graphical format.

[6] USGS Website:
http://waterdata.usgs.gov/ma/nwis/uv?dd_cd=01&format=gif&period=7&site_no=01096000

- Graphical displays of individual reservoirs and the combined reservoir system are shown displaying the water elevation relative to 10, 25, 50, 75 and 90% of the reservoir storage capacity. Using these graphs, operators will know when storage capacities in the system drop, for example, to 50% of its full capacity. The Pennsylvania Drought Method did not designate certain percentages of full capacity; hence the percentages were arbitrarily selected.

- Using the demand (commonly referred to as depletion rate in MGD) and the available storage (in MG), the number of days of remaining storage is computed by dividing the available storage by the depletion rate. Most reservoirs in this study are considered "small" in that they typically refill to full capacity by April 15th of each year. The number of days until April 15th is automatically computed and compared to the number of days of remaining storage to determine if there is a potential shortfall in supply. The following fictitious example best illustrates how the spreadsheet functions (note this example uses a weekly time step, whereas the spreadsheet is set up on a daily time step).

Date	Available Storage (MG)	Depletion Rate (MG/week)	Weeks of Storage Remaining	Weeks until April 15 (days)
6/07	153.8	-	-	-
6/24	151.5	2.3	65	44
6/21	149.0	2.5	60	43
6/28	148.2	2.8	52	42
7/05	142.8	3.4	42	41
7/12	139.2	3.6	39*	40
If the number of weeks until April 15 exceeds the weeks of storage remaining (as is the case on July 12), a drought stage could be triggered.				

When the number of days of storage remaining is less than the number of days for the reservoir to refill (in this analysis, it was assumed that the reservoir would refill by April 15), the spreadsheet will issue a "warning" indicating that supplies are running low. When the warning is issued, the water suppliers can then invoke various water conservation measures aimed at reducing demand (see Drought Contingency Plans).

Another component of the spreadsheet that is not used in the analysis, but may be helpful to the water suppliers is an estimate of net inflow to each reservoir. As described in Section 4.0, water suppliers can indirectly estimate net reservoir inflow by entering the mean daily flow of the Squannacook River from the USGS website. Although the net inflow is not directly used in the spreadsheet analysis it provides operators with current information on the estimated net inflow.

A more detailed description of the spreadsheet input requirements and capabilities are described in Appendix B.

5.0 Summary

This summary report provides general information on the Fitchburg and Leominster Water Supply systems. Of particular importance is the development of a monitoring plan/spreadsheet that will allow the water suppliers to better manage their water supply systems. The spreadsheet will provide the water suppliers with up-to-date information on available storage capacities, percent full, and will issue warnings when suppliers fall below certain trigger levels. The spreadsheet is designed such that the triggers set forth in the Drought Contingency Plans are directly incorporated in the spreadsheet. Thus, when total reservoir storage levels drop below these pre-determined capacities, various warning levels are highlighted and appropriate water conservation measures outlined in the Drought Contingency Plans can be enacted.

In order for the monitoring program to be effective, the USGS staff gages provided to Fitchburg and Leominster must be installed at each of the reservoirs relative to the NGVD 1929 datum. In addition, operating personnel must be willing to collect readings on a daily basis at least during low flow periods, but perhaps less often during periods of plentiful supplies.

6.0 References

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Fennessey, N.M., 1994, A hydro-climatological model of daily streamflow for the northeast United States: Medford, MA, Tufts University, Ph.D. dissertation, variously paged.

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Pennsylvania Department of Environmental Protection- Website. General Guidelines for an Individual Public Water Supply Drought Contingency Plan.
http://www.dep.state.pa.us/dep/subject/hotopics/drought/suppliers.htm

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Public Water Supply Annual Statistical Reports for 1999, 2000, 2001, 2002. Massachusetts Department of Environmental Protection. Fitchburg Water Department.

United States Geological Survey Website:
http://waterdata.usgs.gov/ma/nwis/uv?dd_cd=01&format=gif&period=7&site_no=01096000

Water System Master Study, Maguire Group, City of Leominster Department of Public Works, Final Draft, January 8, 2001.

Figure 1.0-1: Nashua River Basin

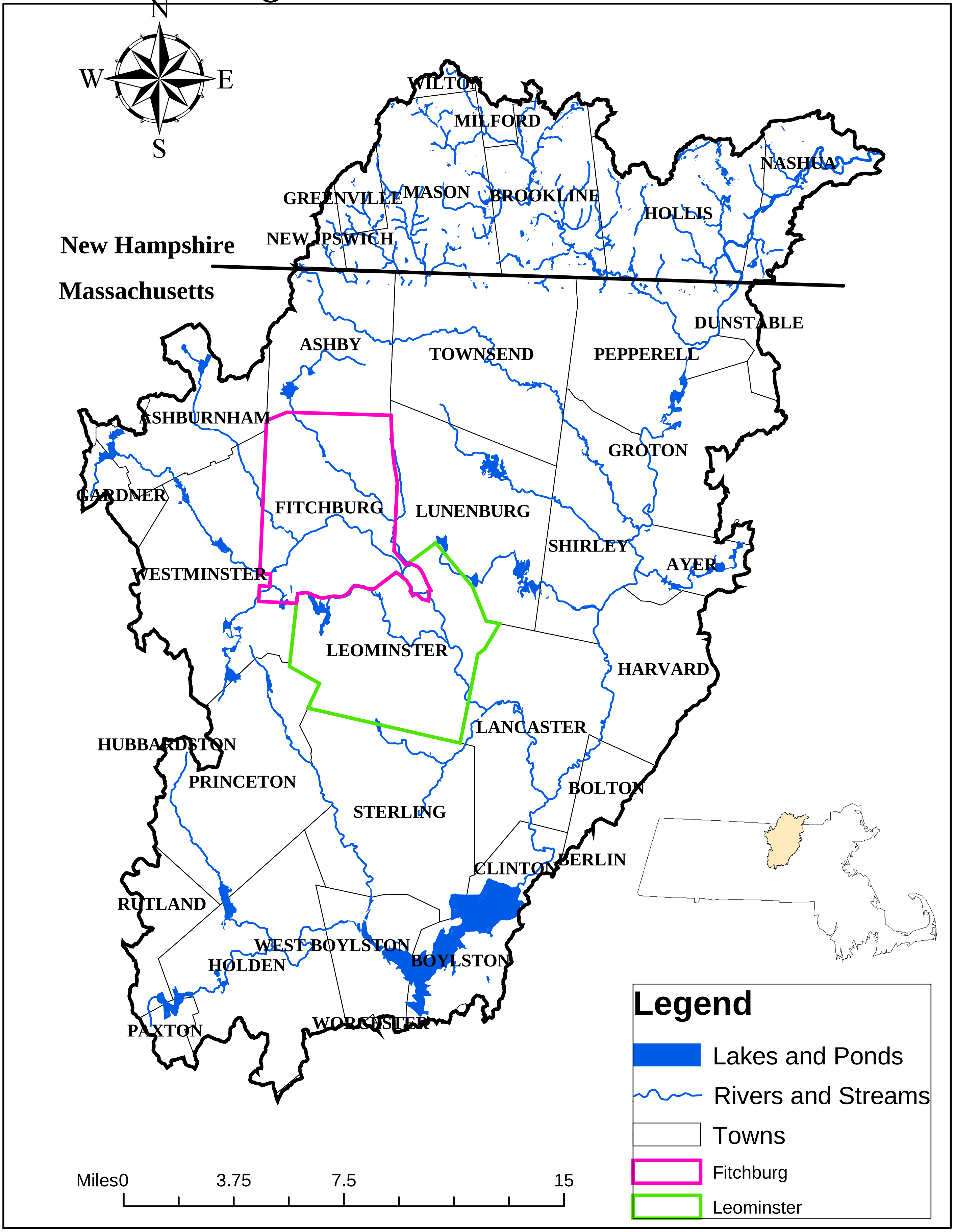


Figure 1.0-2: Fitchburg Reservoir Water Supply System

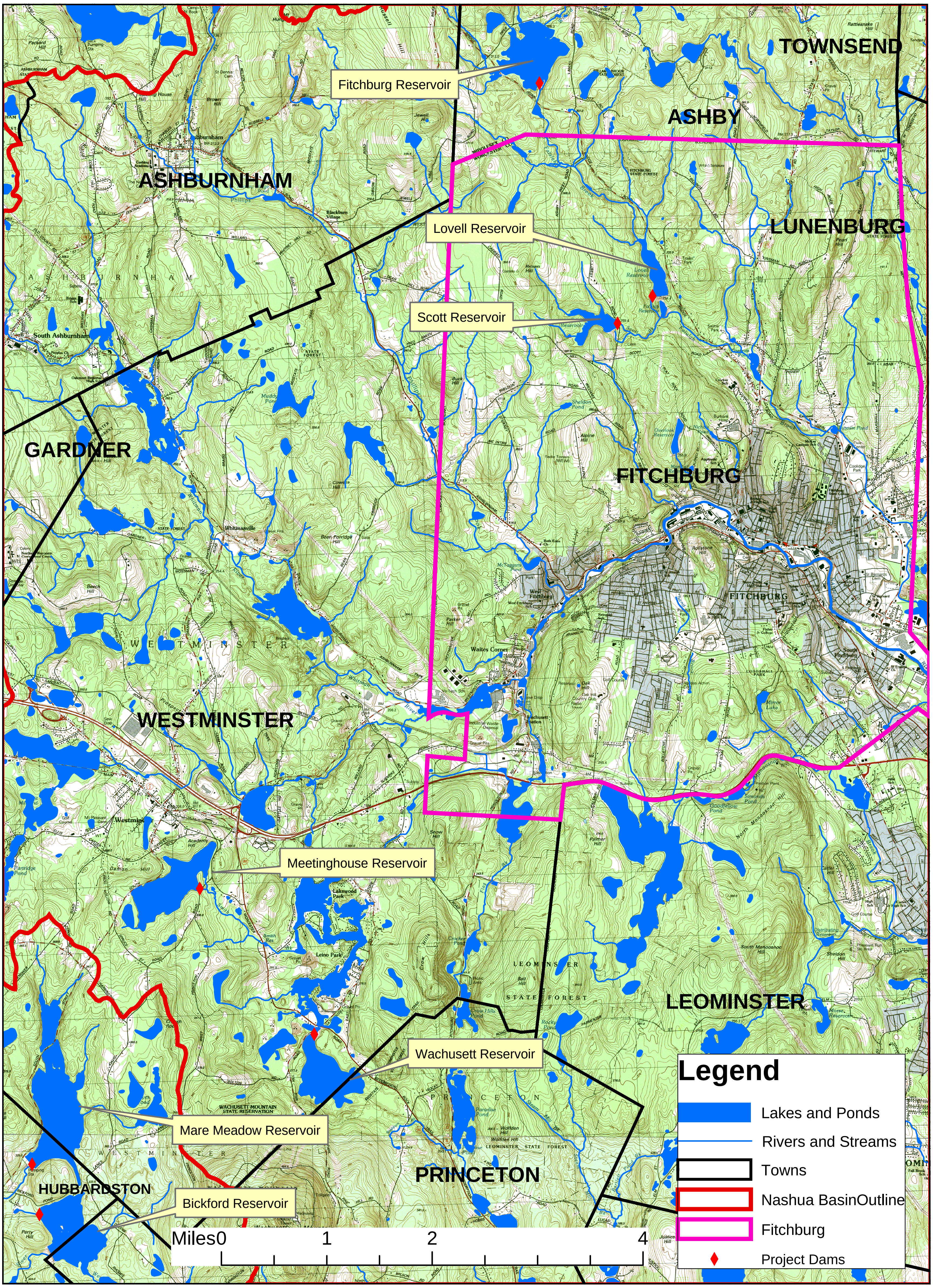
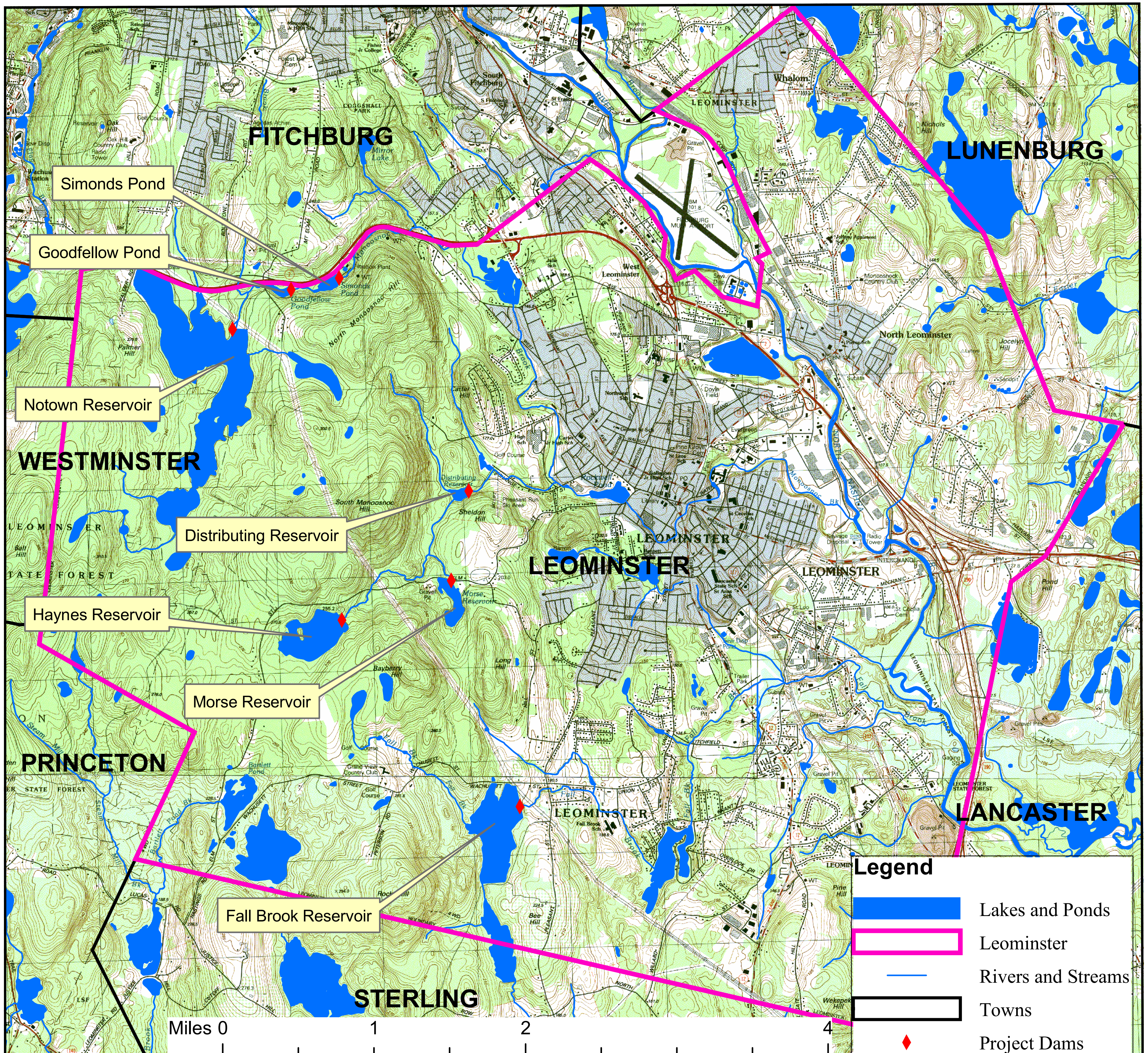


Figure 1.0-3: Leominster Water Supply System



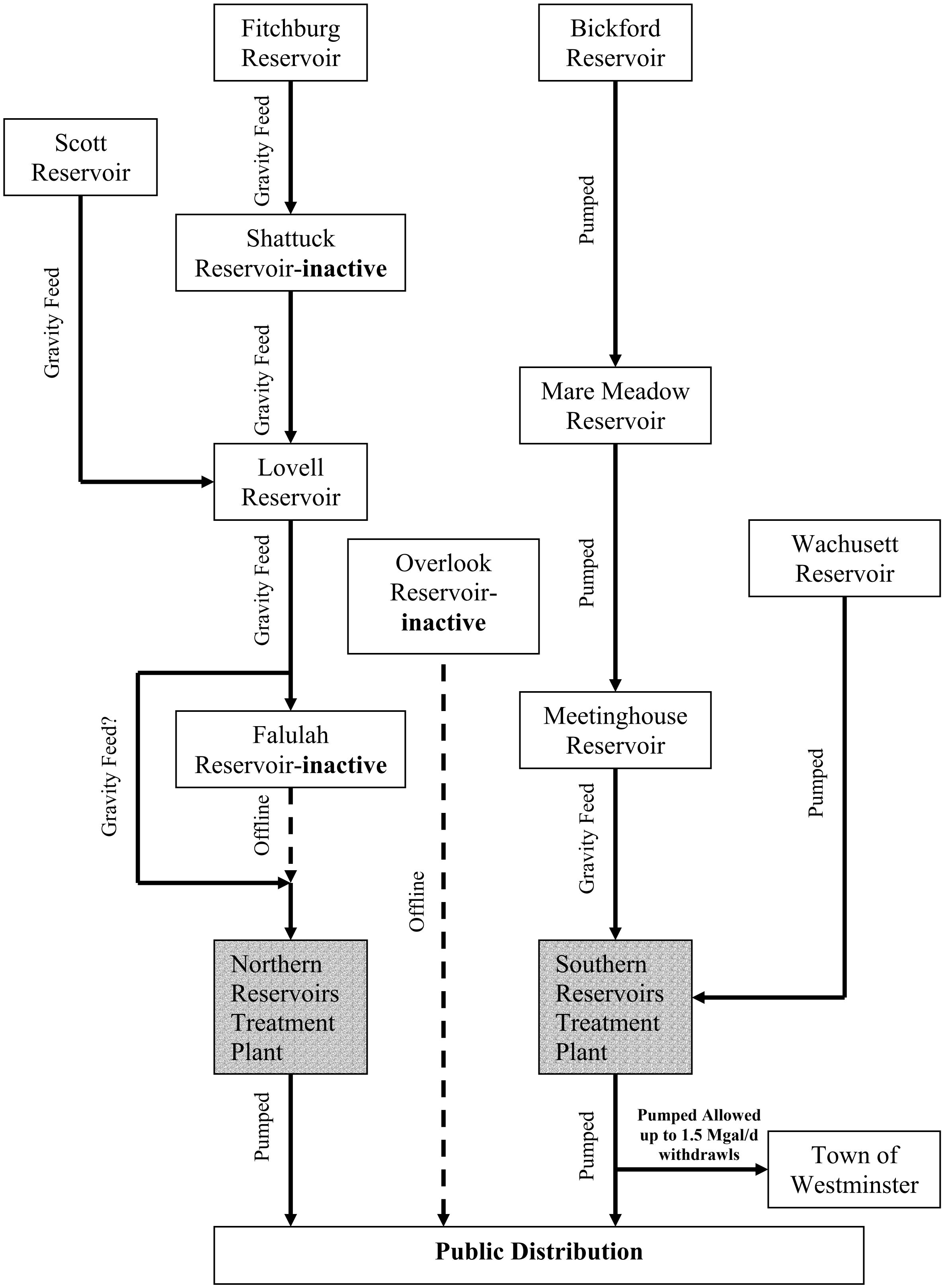


Figure 2.1-1: Fitchburg Reservoir Water Supply System

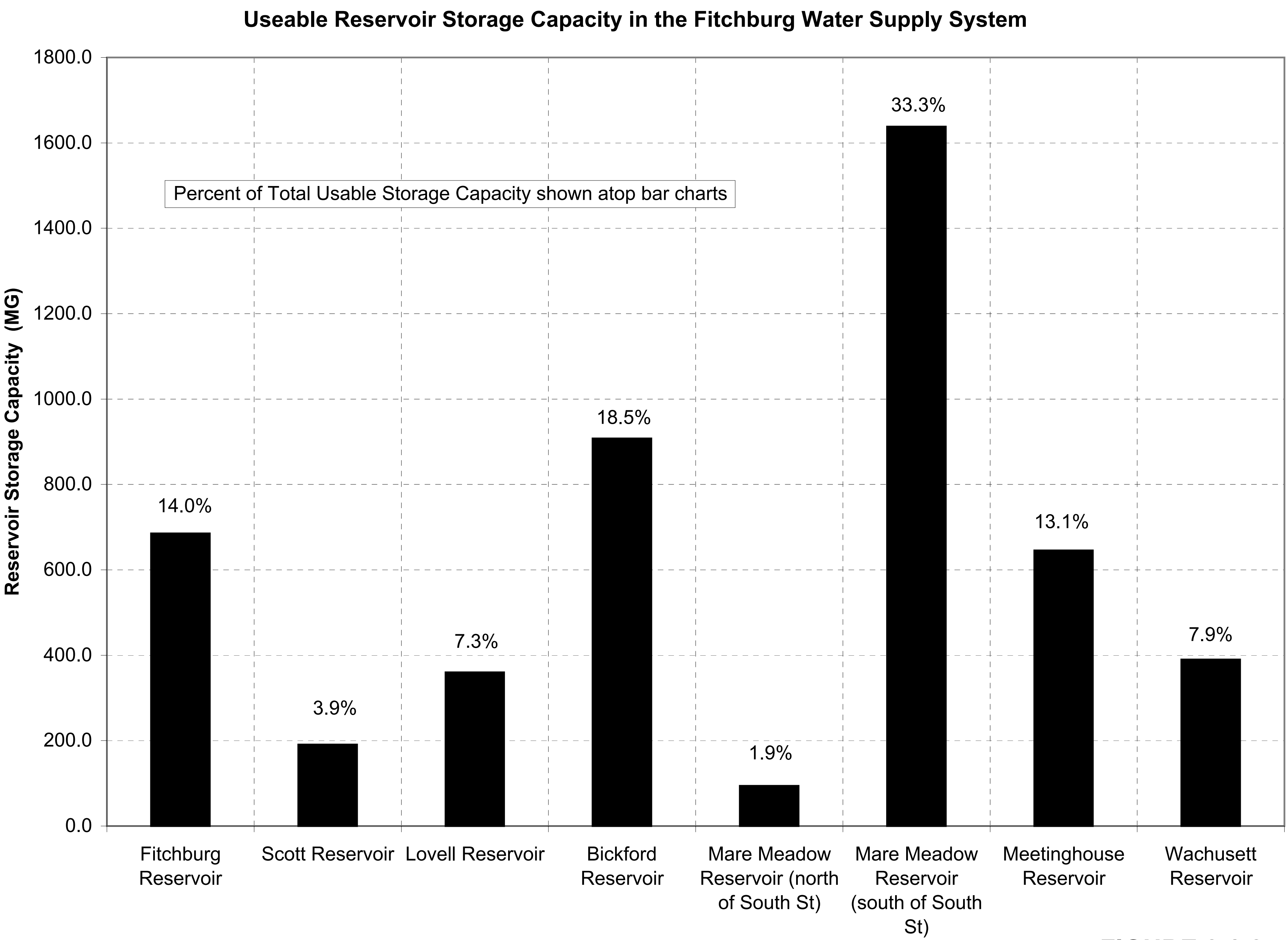

Useable Reservoir Storage Capacity in the Fitchburg Water Supply System
Percent of Total Usable Storage Capacity shown atop bar charts
Reservoir Storage Capacity (MG)
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
14.0%
3.9%
7.3%
18.5%
1.9%
33.3%
13.1%
7.9%
Fitchburg Reservoir
Scott Reservoir
Lovell Reservoir
Bickford Reservoir
Mare Meadow Reservoir (north of South St)
Mare Meadow Reservoir (south of South St)
Meetinghouse Reservoir
Wachusett Reservoir

FIGURE 2.1-2

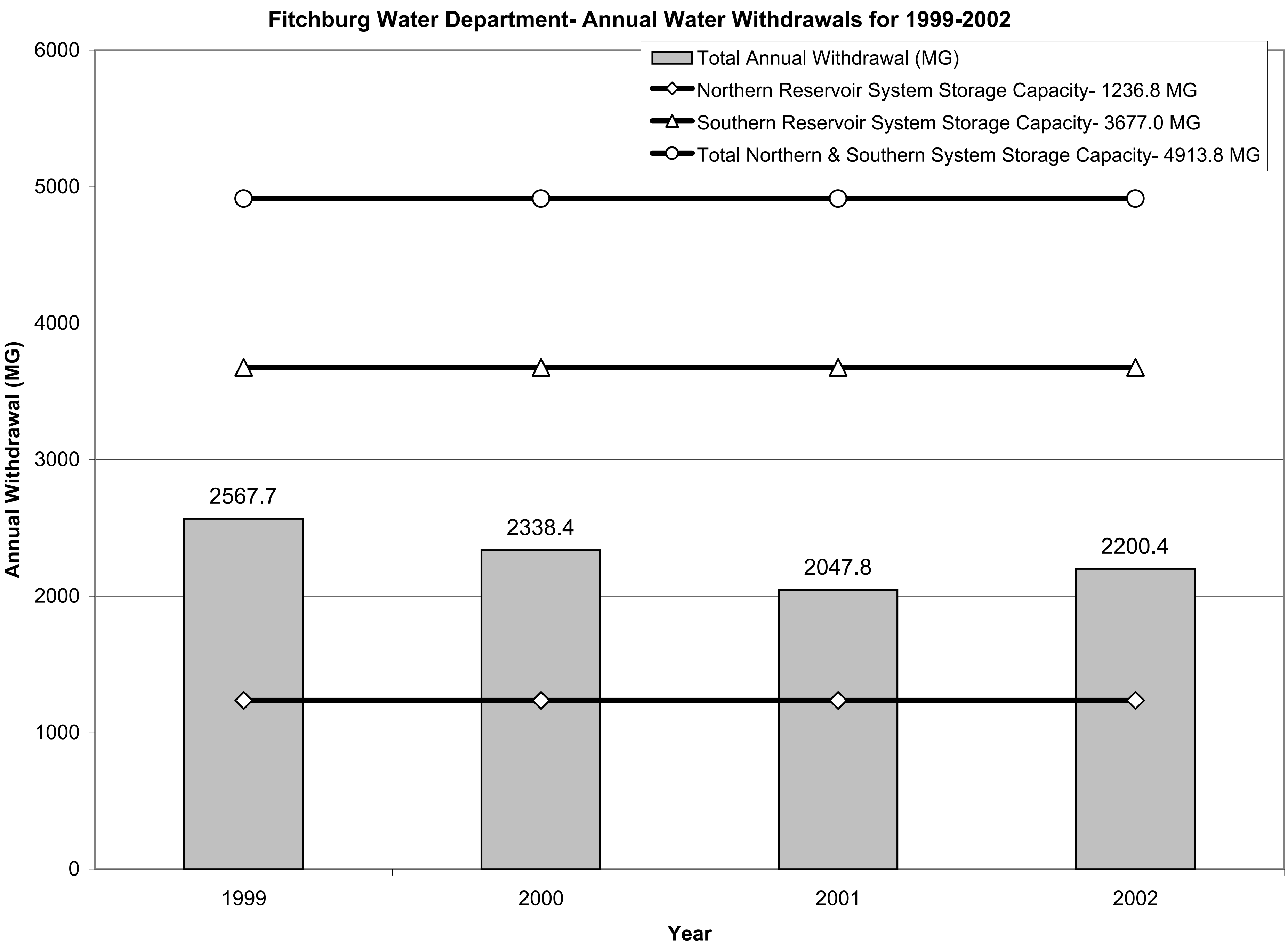

Fitchburg Water Department- Annual Water Withdrawals for 1999-2002
Total Annual Withdrawal (MG)
Northern Reservoir System Storage Capacity- 1236.8 MG
Southern Reservoir System Storage Capacity- 3677.0 MG
Total Northern & Southern System Storage Capacity- 4913.8 MG
6000
5000
4000
3000
2000
1000
0
Annual Withdrawal (MG)
2567.7
2338.4
2047.8
2200.4
1999
2000
2001
2002
Year

FIGURE 2.1.1-1

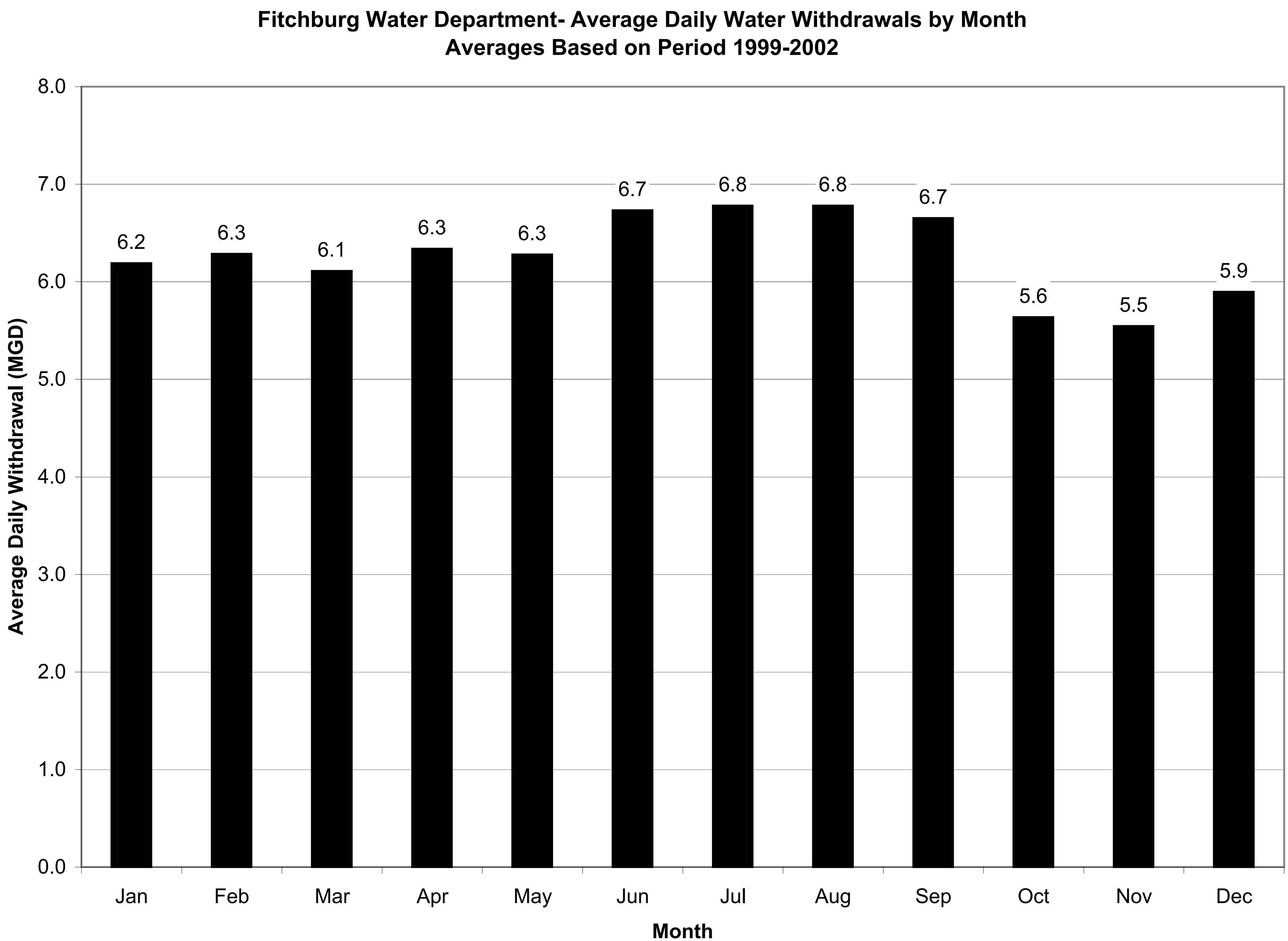

Fitchburg Water Department- Average Daily Water Withdrawals by Month
Averages Based on Period 1999-2002
Average Daily Withdrawal (MGD)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
6.2
6.3
6.1
6.3
6.3
6.7
6.8
6.8
6.7
5.6
5.5
5.9
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

FIGURE 2.1.1-2

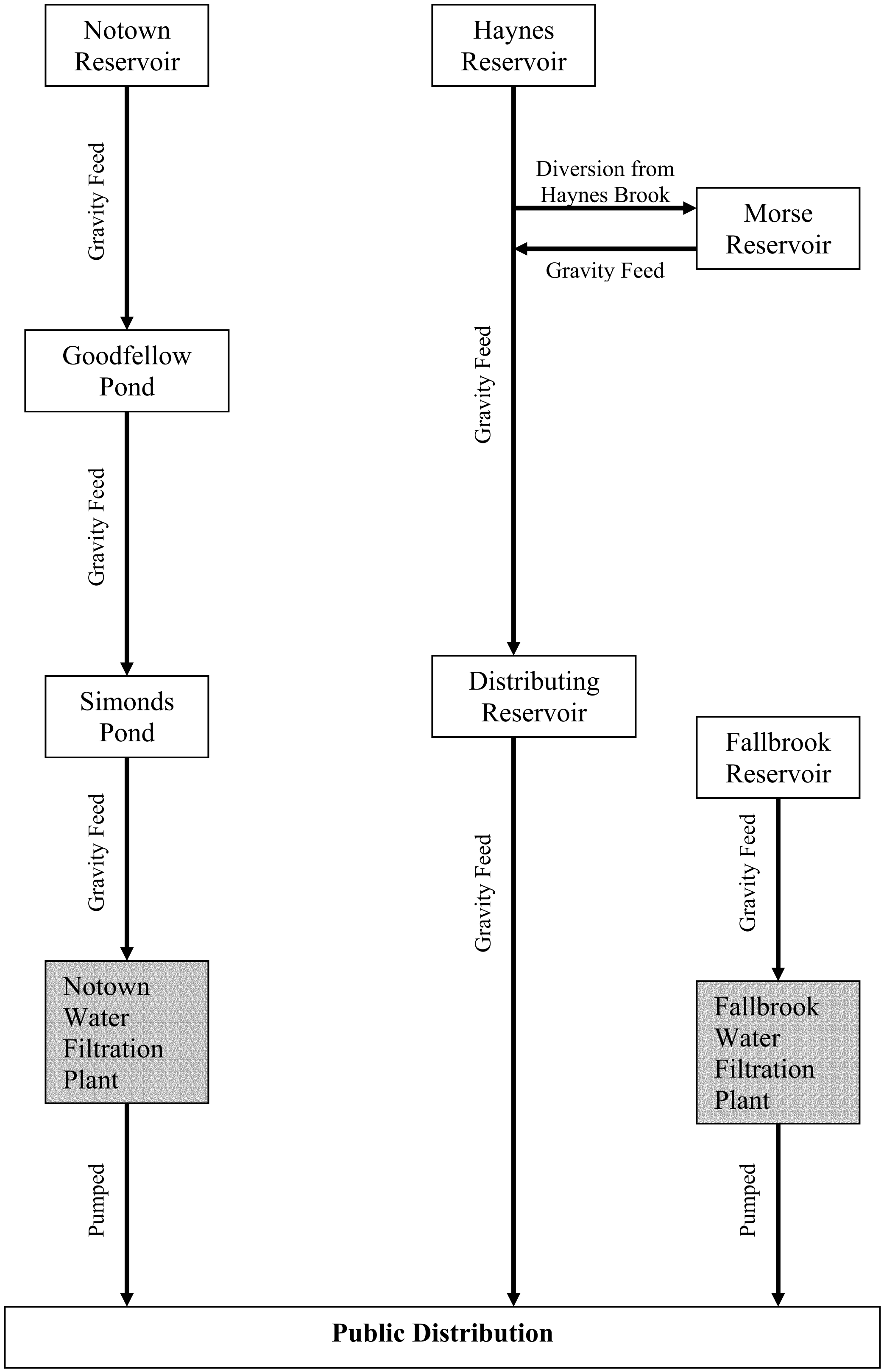


Figure 2.2-1: Leominster Reservoir Water Supply System

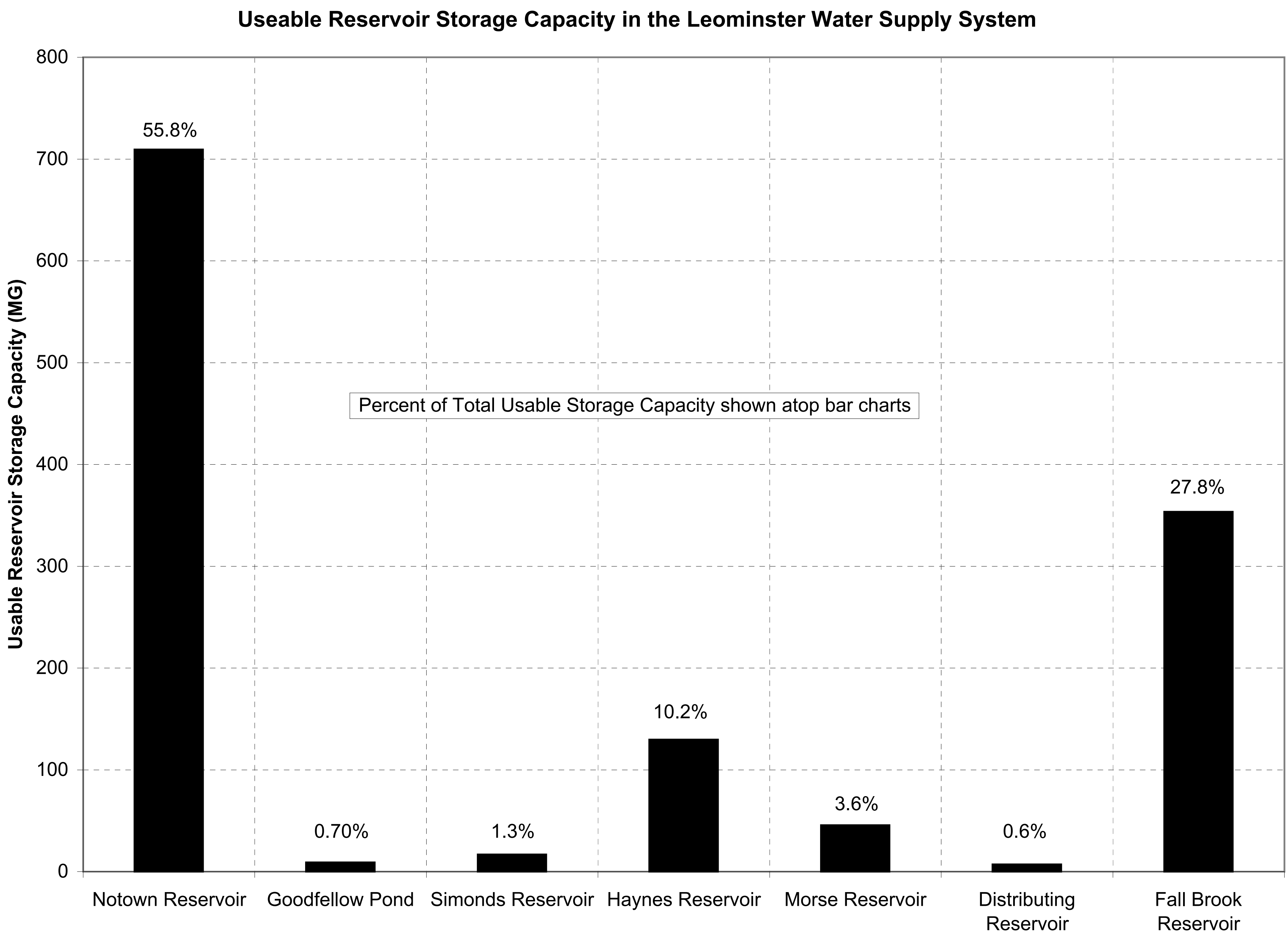
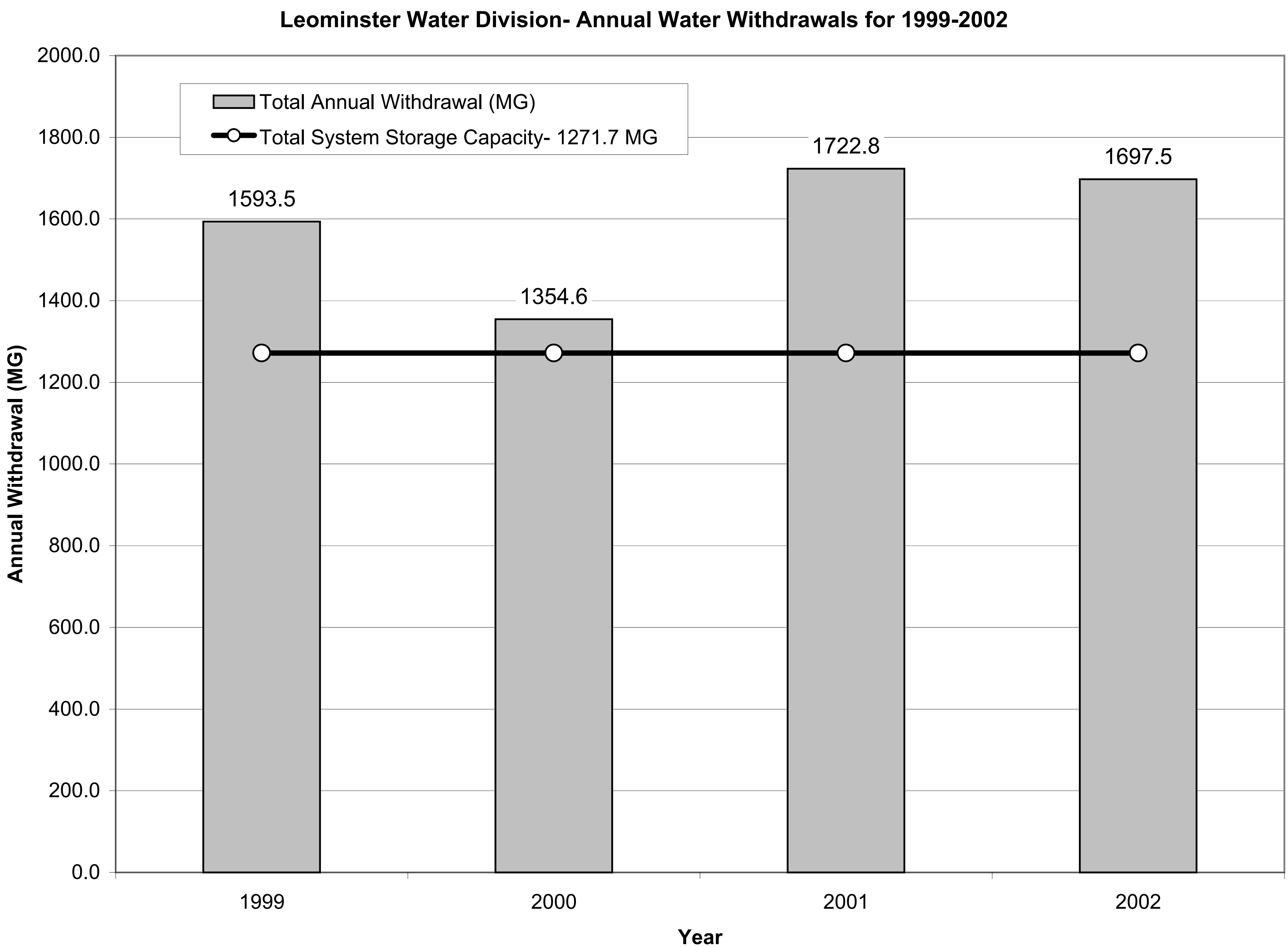

Useable Reservoir Storage Capacity in the Leominster Water Supply System
Usable Reservoir Storage Capacity (MG)
800
700
600
500
400
300
200
100
0
55.8%
0.70%
1.3%
10.2%
3.6%
0.6%
27.8%
Percent of Total Usable Storage Capacity shown atop bar charts
Notown Reservoir
Goodfellow Pond
Simonds Reservoir
Haynes Reservoir
Morse Reservoir
Distributing Reservoir
Fall Brook Reservoir

FIGURE 2.2-2



Leominster Water Division- Annual Water Withdrawals for 1999-2002
Total Annual Withdrawal (MG)
Total System Storage Capacity- 1271.7 MG
1593.5
1354.6
1722.8
1697.5
Annual Withdrawal (MG)
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
1999
2000
2001
2002
Year

FIGURE 2.2.1-1

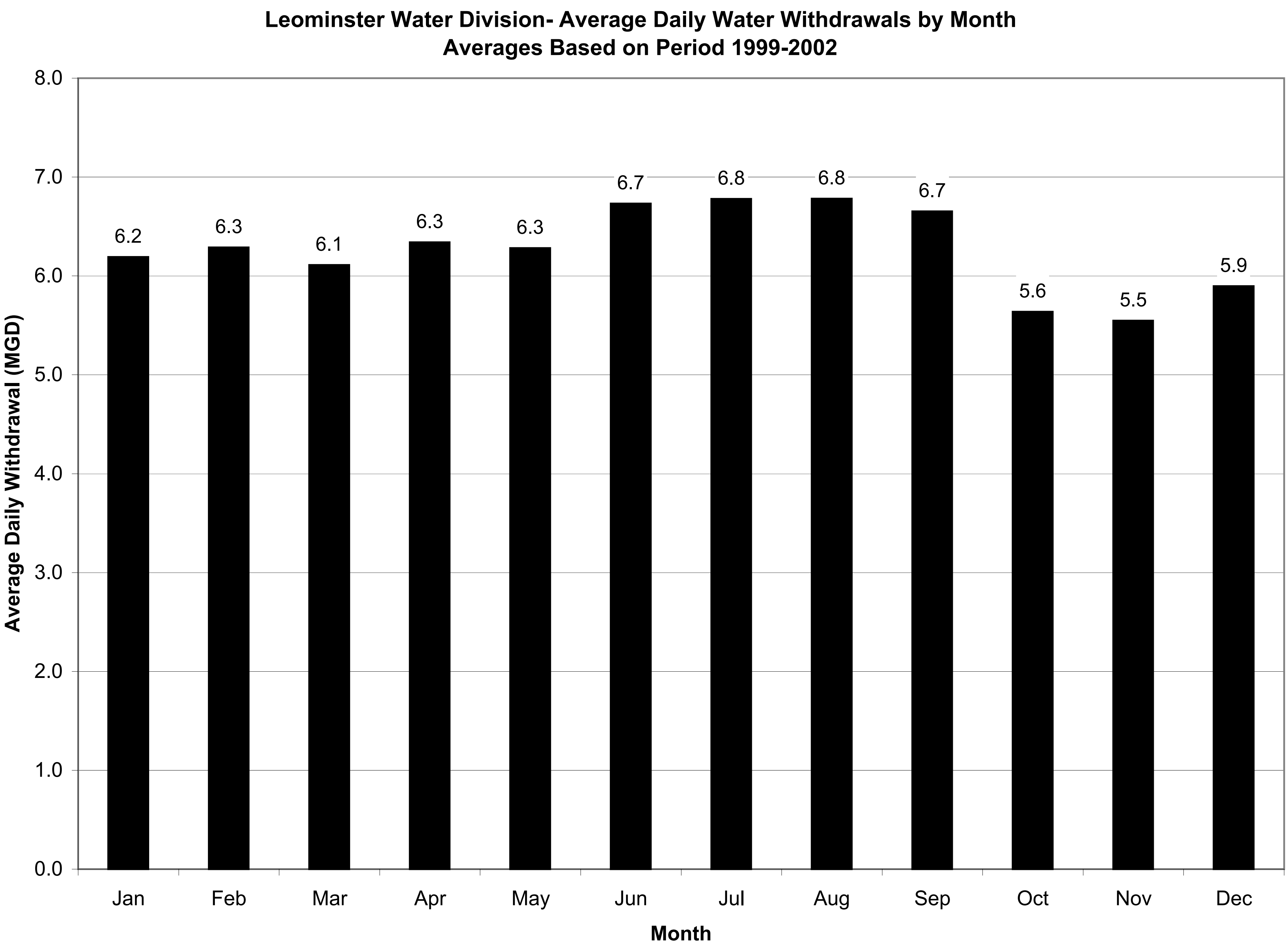

Leominster Water Division- Average Daily Water Withdrawals by Month
Averages Based on Period 1999-2002
Average Daily Withdrawal (MGD)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
6.2
6.3
6.1
6.3
6.3
6.7
6.8
6.8
6.7
5.6
5.5
5.9
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

FIGURE 2.2.1-2

Appendix A: Spreadsheet Instructions and Background

There is one spreadsheet for Fitchburg and Leominster with the following tabs (screen dumps for both the Fitchburg and Leominster Input Tab are attached):

Input Tab
On this tab the user is to enter:

- the reservoir elevation in feet of each reservoir in the system. Note that the datum **must** be National Geodetic Vertical Datum of 1929.
- the daily demand in MGD. If no daily demand is entered the spreadsheet will default to the average monthly demand based on averaging the monthly withdrawals from 1999-2002 and dividing by the number of days in a given month.
- the Squannacook River flow in cfs. The spreadsheet contains a direct link to the Squannacook River flow data as reported on the USGS website. The website provides the instantaneous flow and average daily flow for the previous day. To select the average daily flow click on the following web link:
  http://waterdata.usgs.gov/nwis/dv?format=html&period=31&site_no=01096000
  To select the instantaneous flow (recorded every 15 minutes) click on the following web link:
  http://waterdata.usgs.gov/nwis/uv?format=html&period=7&site_no=01096000

Notes:

1. Only enter data within the orange cells. Do not overwrite other data shown on the Input Tab or any other Tabs.
2. Users **must** enter the reservoir elevation **each day**. If no data is available for a given day, it is recommended that the previous day's reservoir elevation be repeated.

Computed Storages @ each Reservoir Tab
This tab reports information on:

- the storage capacity of each individual reservoir and for the entire system. Storage capacity (in MG) is determined from the reservoir elevation (as provided on the Input tab) versus storage formulas developed by the USGS for each reservoir.
- the percent (%) full is shown for each individual reservoir and for the entire system. This is computed by dividing the available storage capacity by the net storage capacity (as determined by subtracting the storage at the spillway crest from the intake elevation).
- Note that for Fitchburg, additional storage capacities are shown for the Northern and Southern Reservoir systems.
- In their Drought Contingency Plan, Fitchburg has four alert levels depending on the percentage of available storage capacity which varies on a monthly basis as shown below.

Month	Level 1- Water Supply Alert	Level 2- Drought Warning	Level 3- Drought Emergency	Level 4- Severe Drought Emergency
Jan	55%	50%	40%	30%
Feb	58%	53%	43%	33%
Mar	60%	55%	45%	35%
Apr	70%	60%	55%	38%
May	80%	70%	63%	45%
Jun	80%	70%	65%	55%
Jul	78%	68%	63%	55%
Aug	75%	65%	60%	55%
Sep	70%	60%	55%	50%
Oct	60%	55%	50%	45%
Nov	55%	53%	45%	40%
Dec	50%	47%	40%	38%

On the Fitchburg spreadsheet, the program will denote the following "No Warning", "Level 1, "Level 2", "Level 3" or "Level 4" depending on the percentage of available storage capacity of the entire system relative to the above table. For example, if the entire reservoir storage capacity is at 51% capacity on January 1, then the spreadsheet will issue a "Level 1" warning.

Forecast Tab

This tab reports information on:

- Collects information from the Input Tab on System Demand (or Depletion Rate) in MGD;
- Computes the Available Reservoir Storage Capacity (MG);
- Computes the number of days of storage remaining (days) by dividing the Available Reservoir Storage Capacity by the Depletion Rate;
- Determines if the number of days of storage remaining is less than the number of days until April 15 (this date was determined to be when the reservoirs refilled). If storage remaining is less than the number of days until April 15, the program will issue a warning.
- For the Fitchburg system, the above four bullets are provided for the Northern, Southern, and Combined Northern/Southern System.
- Net inflow to each reservoir is estimated using the QPPQ transform equations and the average daily flow as reported on the USGS website for Squannacook River. This information does not enter into any of the computations, but is provided as a guide for the users as to the approximate inflow.

All Reservoirs Tab, Individual Reservoir Tabs

These tabs are plots showing:

- Along the x-axis is the time of year (days) and along the y-axis is storage capacity (MG). A black line shows the current storage capacity. In addition, on the Fitchburg spreadsheet the storage equivalent to Level 1, 2, 3, and 4 is shown. For Leominster, the 10, 25, 50, 75, and 90% storage volumes are shown.

Demand Tab

The demand tab provides:

- the total (all sources) water withdrawals on a monthly basis for years 1999-2002.

- the average monthly water withdrawal based on averaging 1999-2002 monthly withdrawals;
- the average daily demand as computed by dividing the average monthly withdrawal by the corresponding days in each month.

QPPQ Transform Tab

The QPPQ tab includes:

- The equations used to estimate inflow into each of the Fitchburg and Leominster Reservoirs is provided as well as a flow duration curve for the Squannacook River.

Microsoft Excel - Fitchburg Water Supply Monitoring

File Edit View Insert Format Tools Data Window Help

A1 — Only Enter Data in the Orange Colored Cells

Only Enter Data in the Orange Colored Cells

Reservoir Elevation Input Spreadsheet
Note: All elevations must use msl datum.

9	Scott (with flashboards)	883.3	845.3	191.3	0.1	191.2
10	Lovell	764	690.0	360.1	0.0	360.1
11	***Northern Reservoir System***					**1236.8**
12	Bickford	1045	1022.5	1052.0	143.8	908.2
13	Mare Meadow (North)	1060	1052.0	146.1	51.7	94.4
14	Mare Meadow (South)	1060	1030.0	1679.2	40.7	1638.5
15	Meetinghouse	1033	1018.0	955.4	309.9	645.5
16	Wachusett	892.4	882.0	546.3	156.0	390.3
17	***Southern Reservoir System***					**3676.9**
18	***Entire Reservoir System***					**4913.8**

Enter Reservoir Elevations in msl datum

Reservoir Elevations must be between the Spillway Crest elevation and Lowest Intake Elevation (see above table)

For real time 15-minute flow data:
http://waterdata.usgs.gov/ma/nwis/uv?dd_cd=01&format=html

For the previous days average daily flow data:
http://waterdata.usgs.gov/ma/nwis/dv?format=html&period=31

USGS 01096000 SQUANNACOOK RIVER NEAR WE

Squannacook River Input Spreadsheet
Enter the Average Daily Flow in cfs

		Elevation Input Data (msl)										
		Northern Reservoir System			Southern Reservoir System							
24	Date	Fitchburg	Scott	Lovell	Bickford	Mare Meadow North	Mare Meadow South	Meetinghouse	Wachusett	Squannacook Gage Flow (cfs)	Squannacook Gage Flow (MGD)	Exceedence Flow (%)
25	1-Jan	1007	883.3	764	1045	1060	1060	1033	892.4	203	131	0.1448
26	2-Jan	1006	882.3	763	1044	1059	1059	1032	891.4	177	114	0.1775
27	3-Jan	1005	881.3	762	1043	1058	1058	1031	890.4	164	106	0.1968
28	4-Jan	1005	881.3	762	1043	1058	1058	1031	890.4	175	113	0.1798
29	5-Jan	1005	881.3	762	1043	1058	1058	1031	890.4	197	127	0.1522
30	6-Jan	1005	881.3	762	1043	1058	1058	1031	890.4	192	124	0.1582
31	7-Jan	1005	881.3	762	1043	1058	1058	1031	890.4	160	103	0.2045
32	8-Jan	1005	881.3	762	1043	1058	1058	1031	890.4	176	114	0.1787
33	9-Jan	1005	881.3	762	1043	1058	1058	1031	890.4	212	137	0.1343
34	10-Jan	1005	881.3	762	1043	1058	1058	1031	890.4	157	101	0.2101
35	11-Jan	1005	881.3	762	1043	1058	1058	1031	890.4	87	56	0.4110
36	12-Jan									90	58	0.3966
37	13-Jan	1007	883.3	764	1045	1060	1060	1033		99	64	0.3632
38	14-Jan	1006	882.3	763	1044	1059	1059	1032		105	68	0.3414
39	15-Jan	1005	881.3	762	1043	1058	1058	1031		86	55	0.4150
40	16-Jan	986								75	48	0.4615
41	17-Jan									69	45	0.4890
42	18-Jan									72	46	0.4749
43	19-Jan									76	49	0.4570
44	20-Jan	1007	883.3	764	1045	1060	1060	1033		72	46	0.4749

Input / Computed Storages @ each Res / Forecast / All Reservoirs / Northern Res / Sou

Ready NUM

Microsoft Excel - Leominster Water Supply Monitoring

File Edit View Insert Format Tools Data Window Help

I24

Only Enter Data in the Orange Colored Cells

Reservoir Elevation Input Spreadsheet
Note: All elevations must use msl datum.

Raw Data- DO NOT MODIFY

Reservoir	Spillway Crest El, NGVD(feet)	Lowest Intake El, msl (feet)	Storage Volume @ Spillway Crest(MG)	Storage Volume @ Lowest Intake (MG)	Net Available Storage Volume (MG)	Spillway Crest El, Local Datum (feet)
Notown	733.8	718.9	707.7	-1.8	709.5	
Goodfellow	713.3	700.0	9.2	0.0	9.2	
Simonds	690.1	672.0	16.8	0.0	16.8	
Haynes	839.6	828.6	129.8	0.0	129.8	
Morse	672.8	650.4	45.7	0.0	45.7	
Distributing	579	560.5	7.1	0.0	7.1	
Fall Brook	651.5	635.0	393.3	39.7	353.6	
Total Storage Capacity in					1271.7	

Enter Reservoir Elevations in msl datum

Reservoir Elevations must be between the Spillway Crest elevation and Lowest Intake Elevation (see above table)

	Elevation Input Data (msl)						
Date	Notown	Goodfellow	Simonds	Haynes	Morse	Distributing	Fall Brook
1-Jan	733.8	713.3	690.1	839.6	672.8	579	651.5
2-Jan							
3-Jan							
4-Jan							
5-Jan							
6-Jan							
7-Jan							
8-Jan							
9-Jan							
10-Jan							
11-Jan							
12-Jan							
13-Jan							
14-Jan							
15-Jan							
16-Jan							
17-Jan							

For real time 15-minute flow data:
http://waterdata.usgs.gov/ma/nwis/uv?dd_cd=01&format=html&period=7&site_no=01

For the previous days average daily flow data:
http://waterdata.usgs.gov/ma/nwis/dv?format=html&period=31&site_no=01096000

USGS 01096000 SQUANNACOOK RIVER NEAR WEST GROTON, MA

Squannacook River Input Spreadsheet
Enter the Average Daily Flow in cfs

System Demand, D

Squannacook Gage Flow (cfs)	Squannacook Gage Flow (MGD)	Exceedence Flow (%)	System Demand (MGD)
203	131	0.1448	3.96
177	114	0.1775	3.96
164	106	0.1968	3.96
175	113	0.1798	3.96
197	127	0.1522	3.96
192	124	0.1582	3.96
160	103	0.2045	3.96
176	114	0.1787	3.96
212	137	0.1343	3.96
157	101	0.2101	3.96
87	56	0.4110	3.96
90	58	0.3966	3.96
99	64	0.3632	3.96
105	68	0.3414	3.96
86	55	0.4150	3.96
75	48	0.4615	3.96
69	45	0.4890	3.96

Input Data / Computed Storages @ each Res / Forecast & Inflows / All Reservoirs / Not

Ready NUM

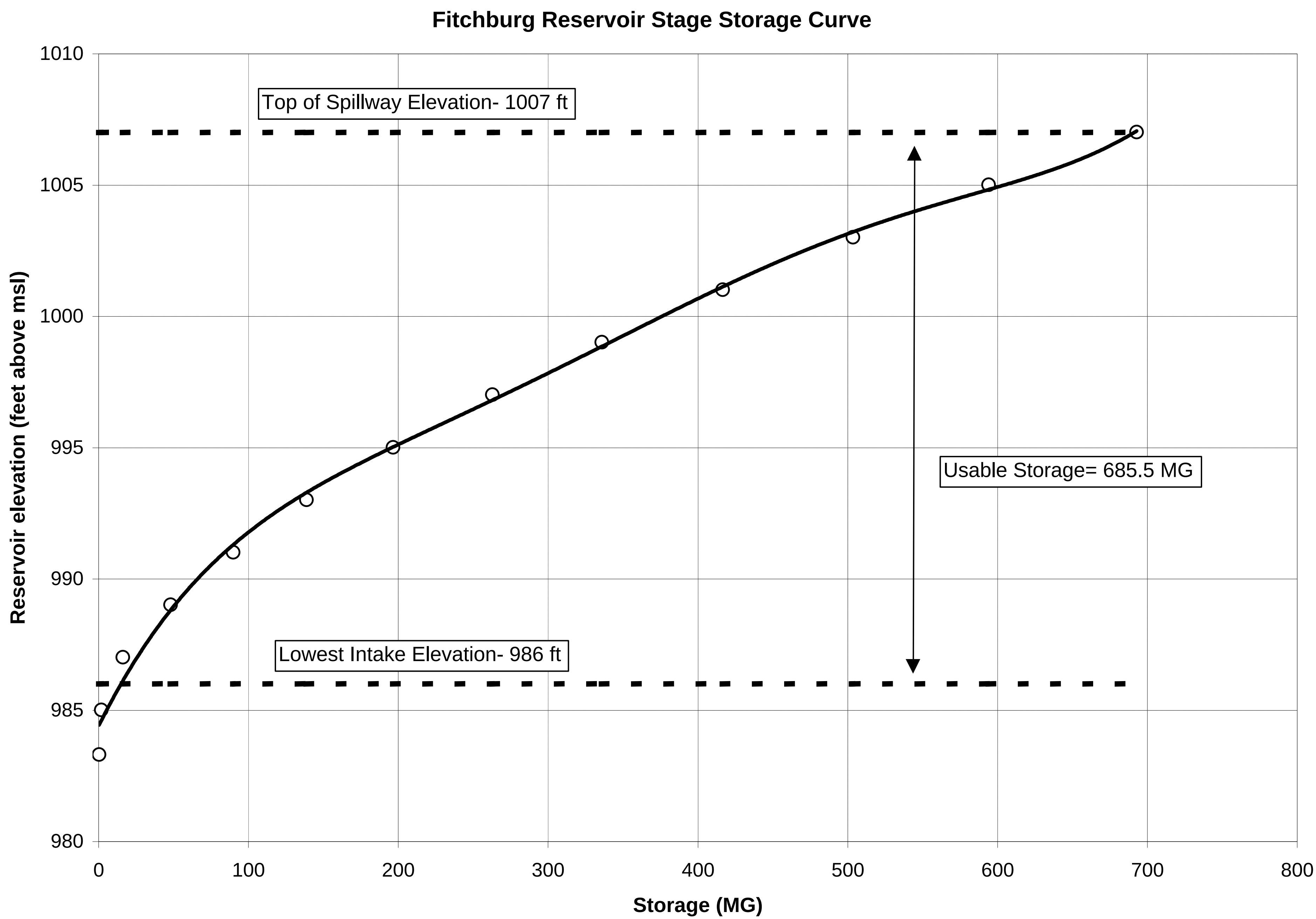
Appendix B: Reservoir Elevation (Stage) versus Storage Curves

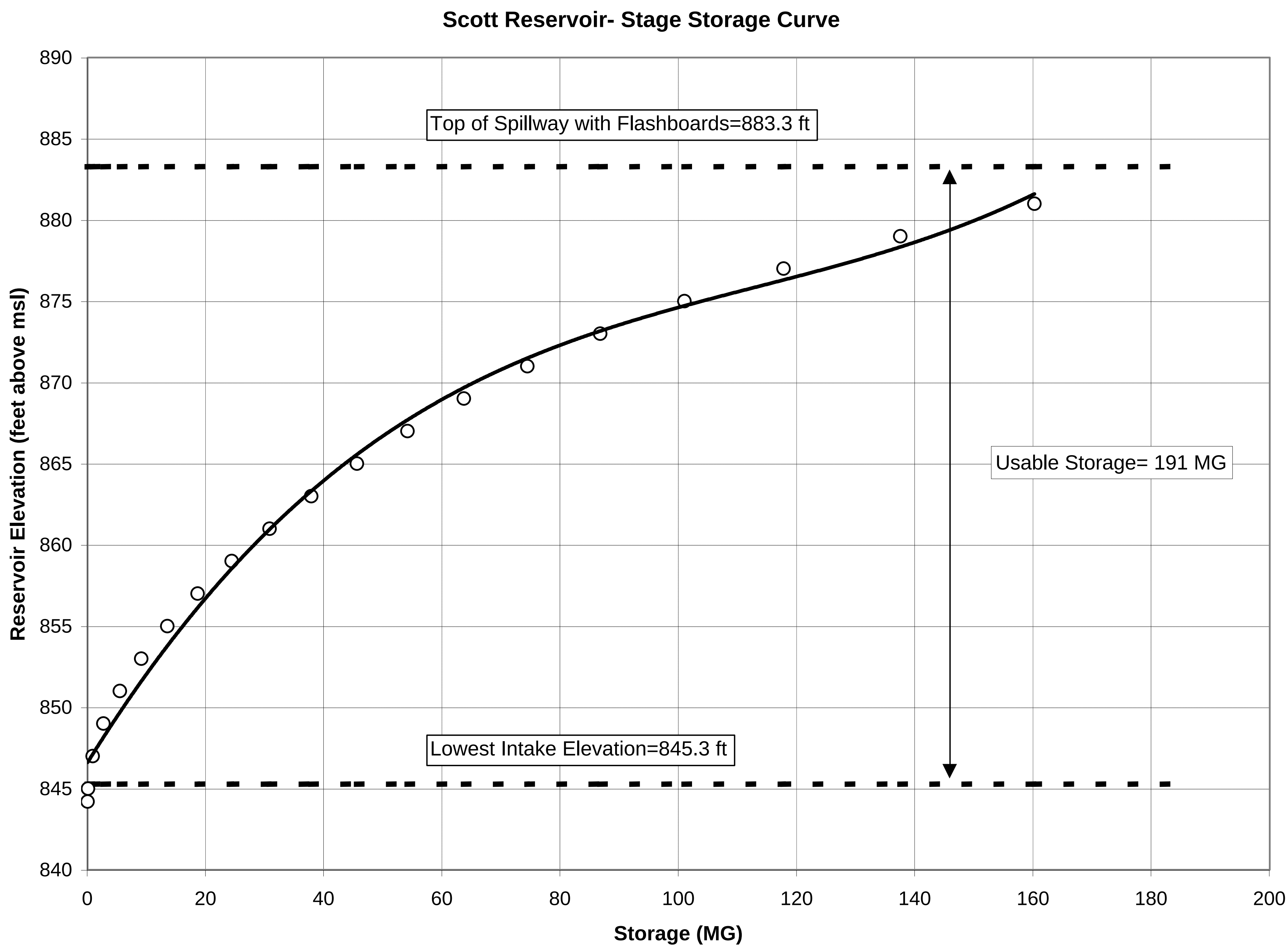
Fitchburg Reservoir- Reservoir Elevation versus Storage Curves

- Fitchburg Reservoir
- Scott Reservoir
- Lovell Reservoir
- Bickford Reservoir
- Mare Meadow Reservoir (small portion)
- Mare Meadow Reservoir (large portion)
- Meetinghouse Reservoir
- Wachusett Reservoir

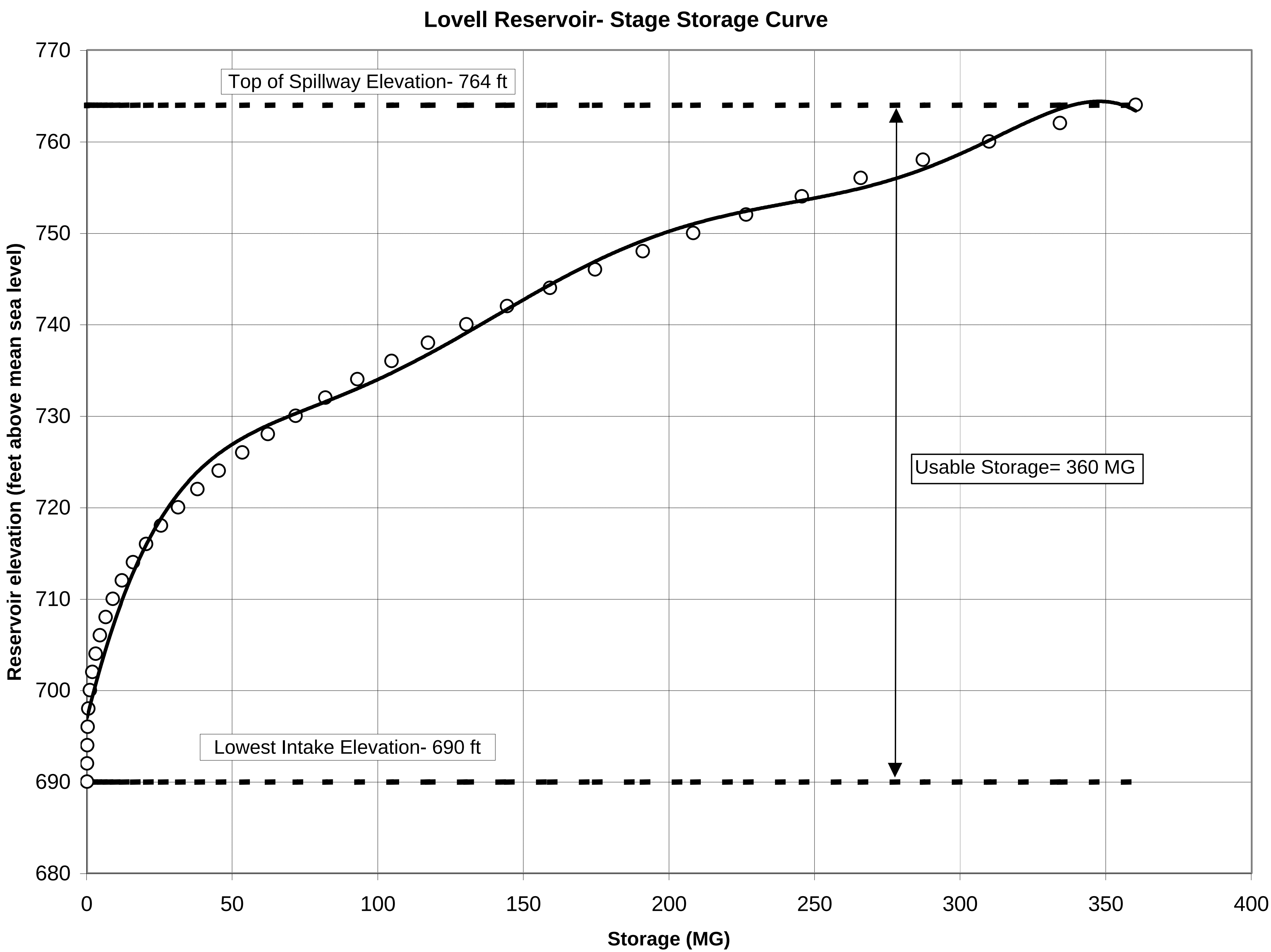
Leominster Reservoirs- Reservoir Elevation versus Storage Curves

- Notown Reservoir
- Goodfellow Pond
- Simonds Pond
- Haynes Reservoir
- Morse Reservoir
- Distributing Reservoir
- Fallbrook Reservoir

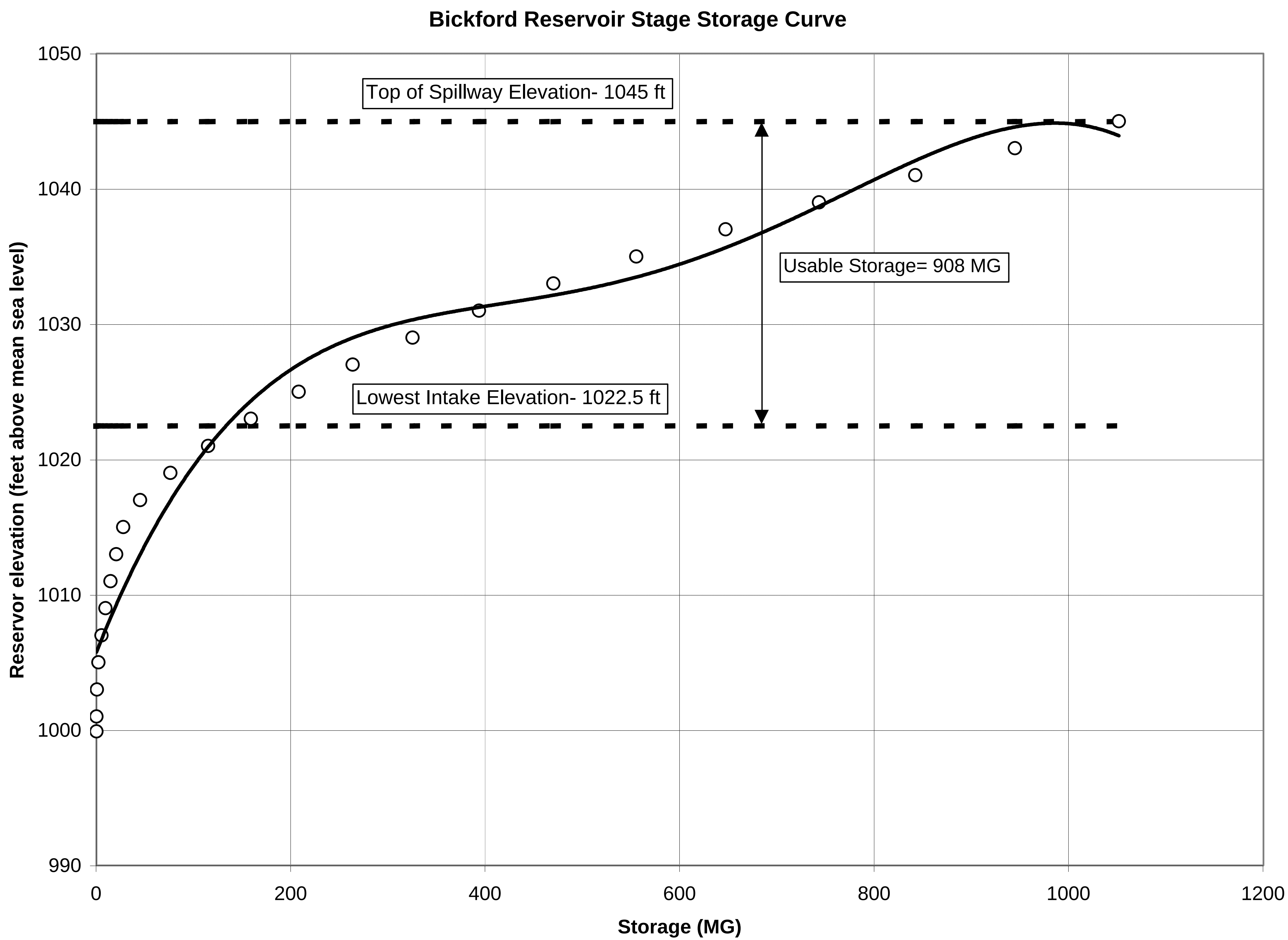

Fitchburg Reservoir Stage Storage Curve
Top of Spillway Elevation- 1007 ft
Usable Storage= 685.5 MG
Lowest Intake Elevation- 986 ft
Reservoir elevation (feet above msl)
Storage (MG)
1010
1005
1000
995
990
985
980
0
100
200
300
400
500
600
700
800



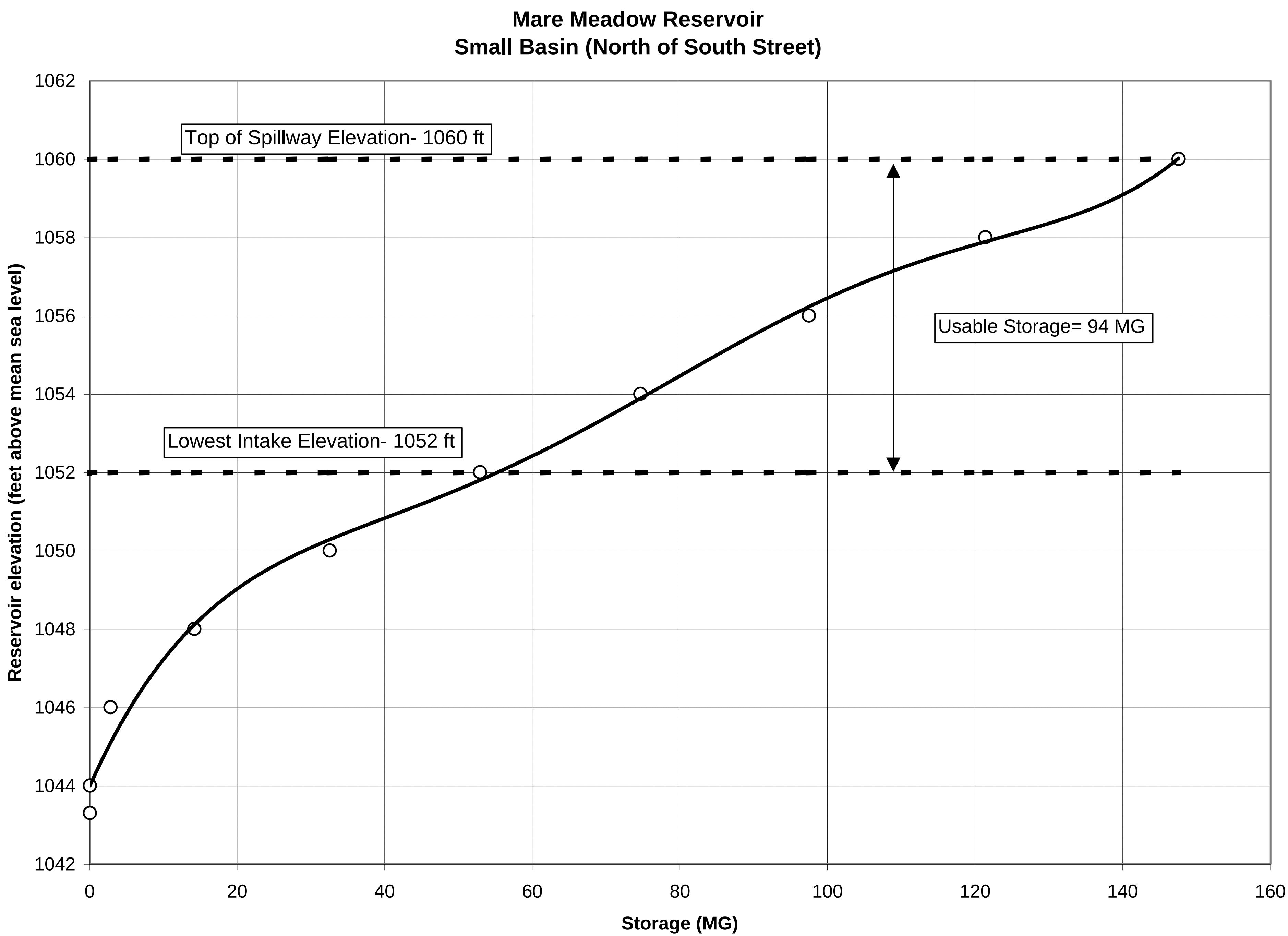
Scott Reservoir- Stage Storage Curve
Top of Spillway with Flashboards=883.3 ft
Usable Storage= 191 MG
Lowest Intake Elevation=845.3 ft
Reservoir Elevation (feet above msl)
Storage (MG)
890
885
880
875
870
865
860
855
850
845
840
0
20
40
60
80
100
120
140
160
180
200



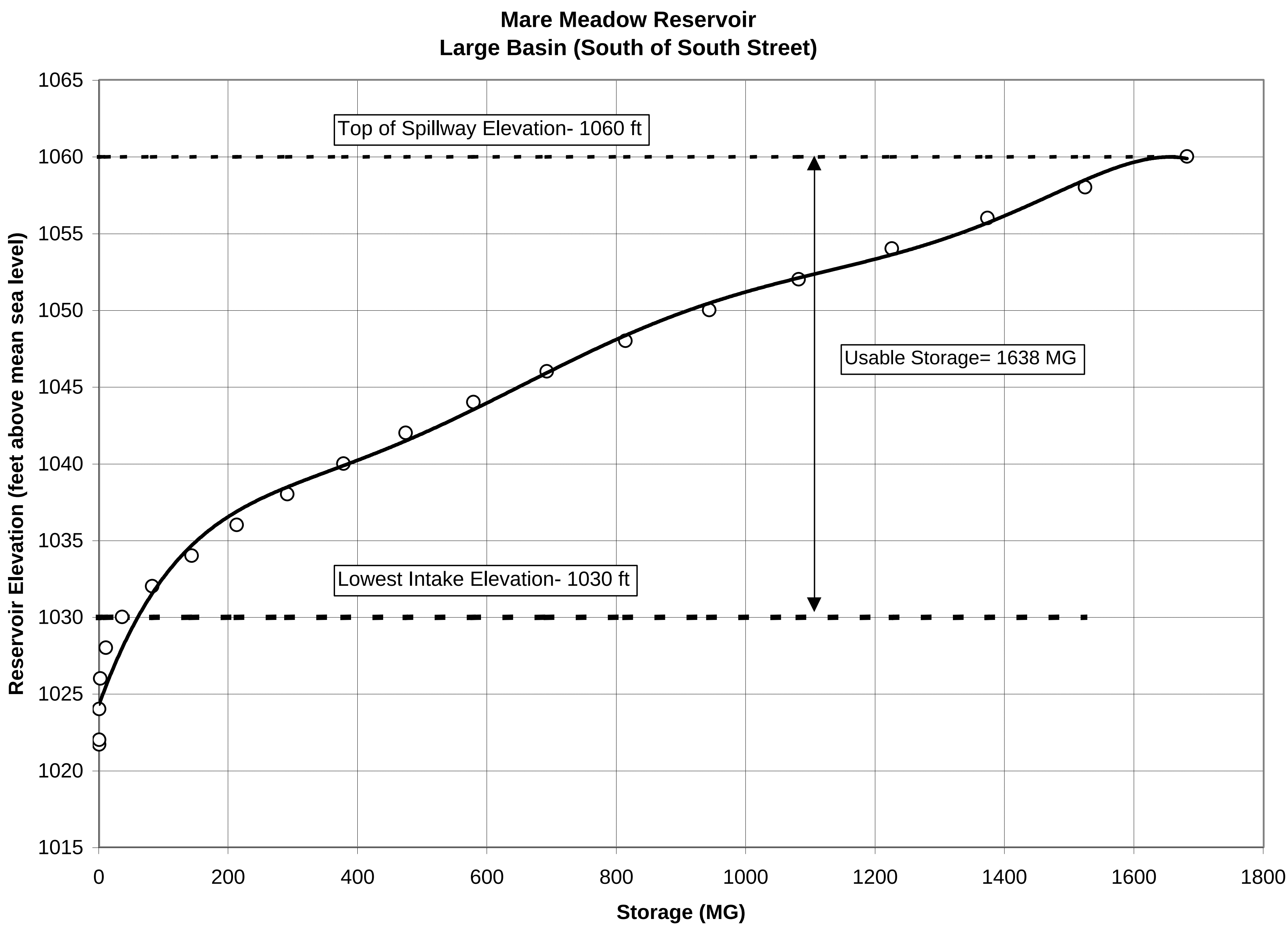
Lovell Reservoir- Stage Storage Curve
Top of Spillway Elevation- 764 ft
Usable Storage= 360 MG
Lowest Intake Elevation- 690 ft
Reservoir elevation (feet above mean sea level)
Storage (MG)
770
760
750
740
730
720
710
700
690
680
0
50
100
150
200
250
300
350
400

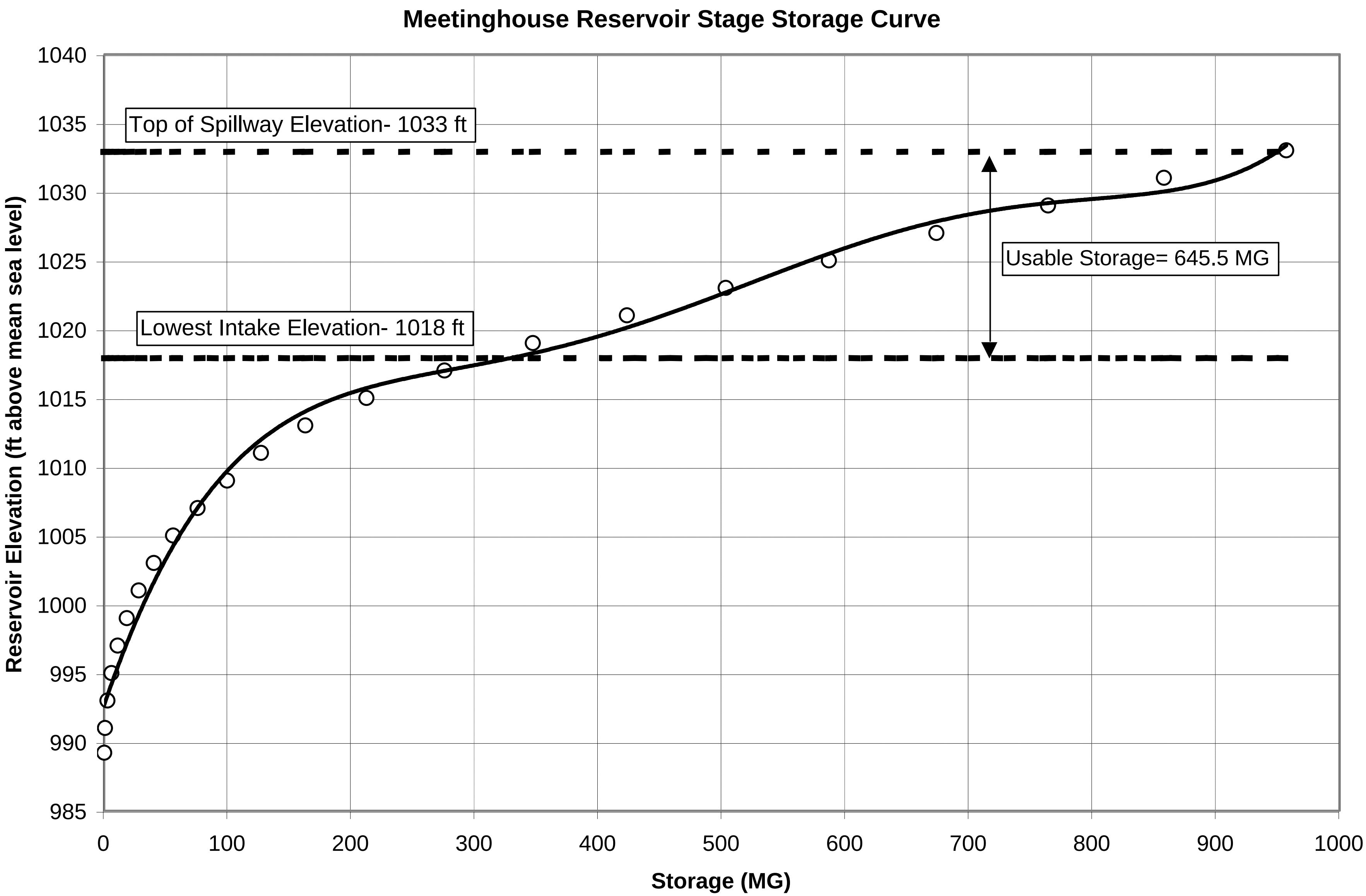


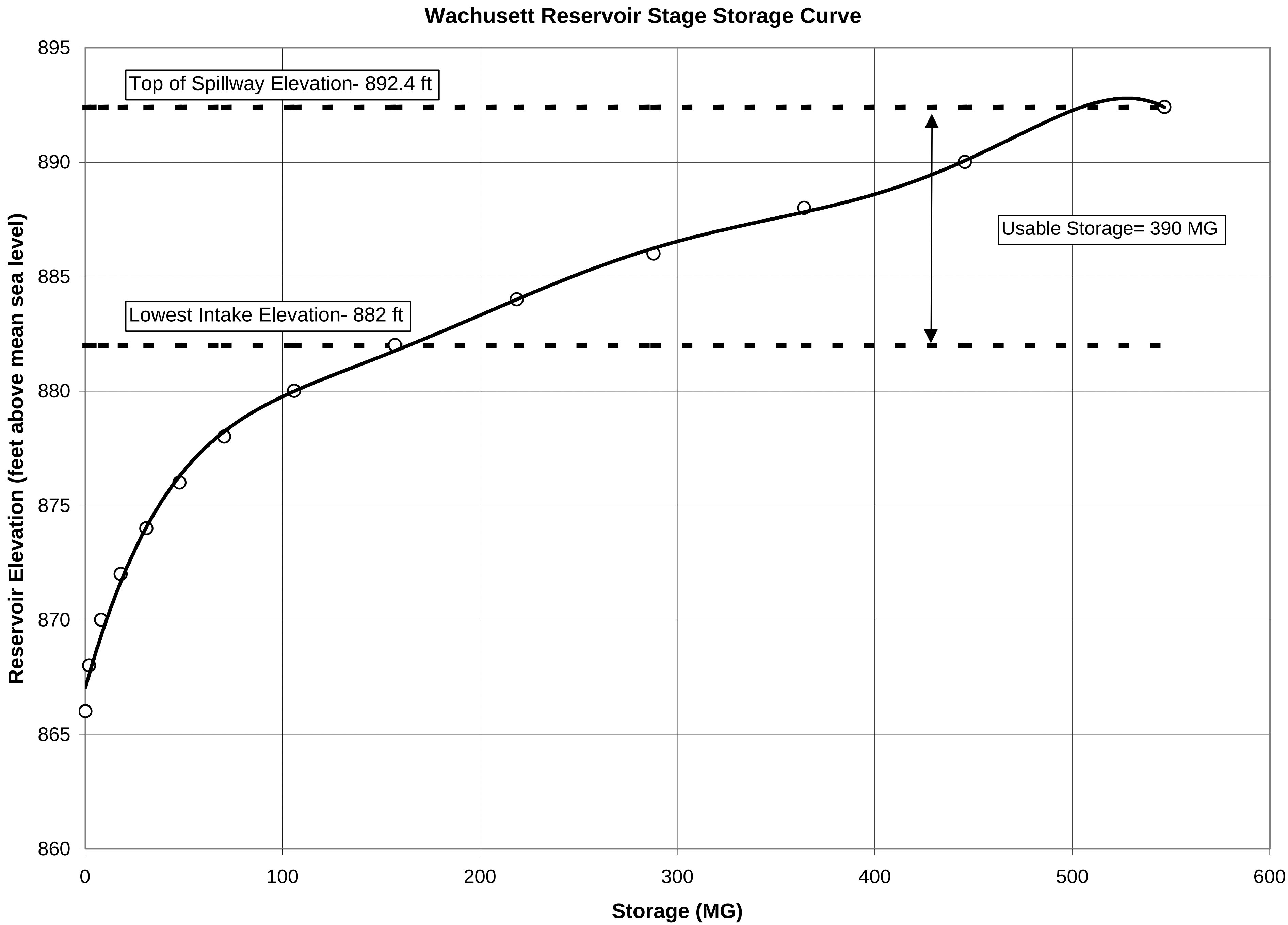
Bickford Reservoir Stage Storage Curve
Top of Spillway Elevation- 1045 ft
Usable Storage= 908 MG
Lowest Intake Elevation- 1022.5 ft
Reservor elevation (feet above mean sea level)
Storage (MG)
1050
1040
1030
1020
1010
1000
990
0
200
400
600
800
1000
1200



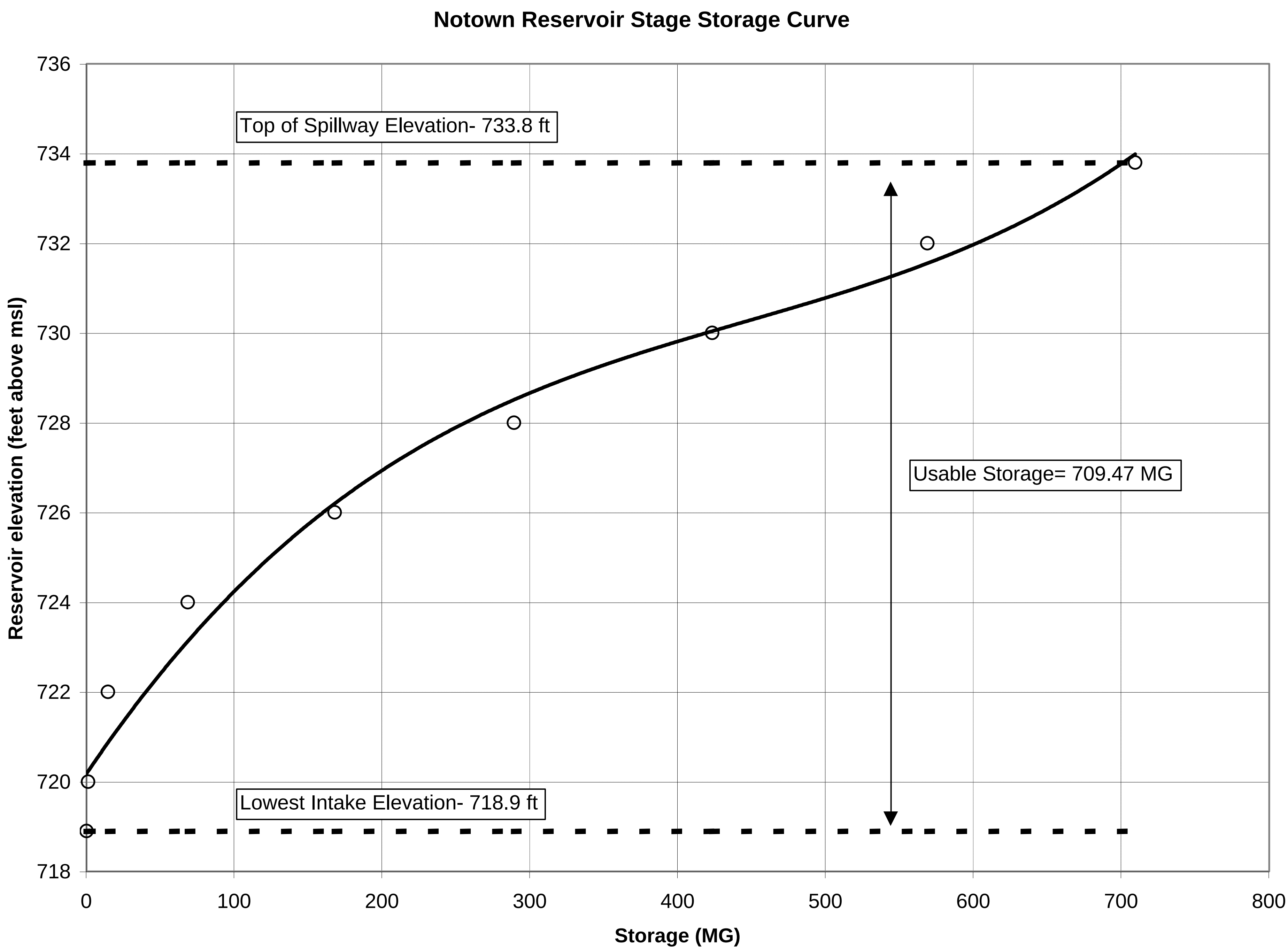
Mare Meadow Reservoir
Small Basin (North of South Street)
Top of Spillway Elevation- 1060 ft
Lowest Intake Elevation- 1052 ft
Usable Storage= 94 MG
Reservoir elevation (feet above mean sea level)
Storage (MG)
1042
1044
1046
1048
1050
1052
1054
1056
1058
1060
1062
0
20
40
60
80
100
120
140
160


Mare Meadow Reservoir
Large Basin (South of South Street)
Top of Spillway Elevation- 1060 ft
Usable Storage= 1638 MG
Lowest Intake Elevation- 1030 ft
Reservoir Elevation (feet above mean sea level)
Storage (MG)
1065
1060
1055
1050
1045
1040
1035
1030
1025
1020
1015
0
200
400
600
800
1000
1200
1400
1600
1800


Meetinghouse Reservoir Stage Storage Curve
Top of Spillway Elevation- 1033 ft
Usable Storage= 645.5 MG
Lowest Intake Elevation- 1018 ft
Reservoir Elevation (ft above mean sea level)
1040
1035
1030
1025
1020
1015
1010
1005
1000
995
990
985
0
100
200
300
400
500
600
700
800
900
1000
Storage (MG)

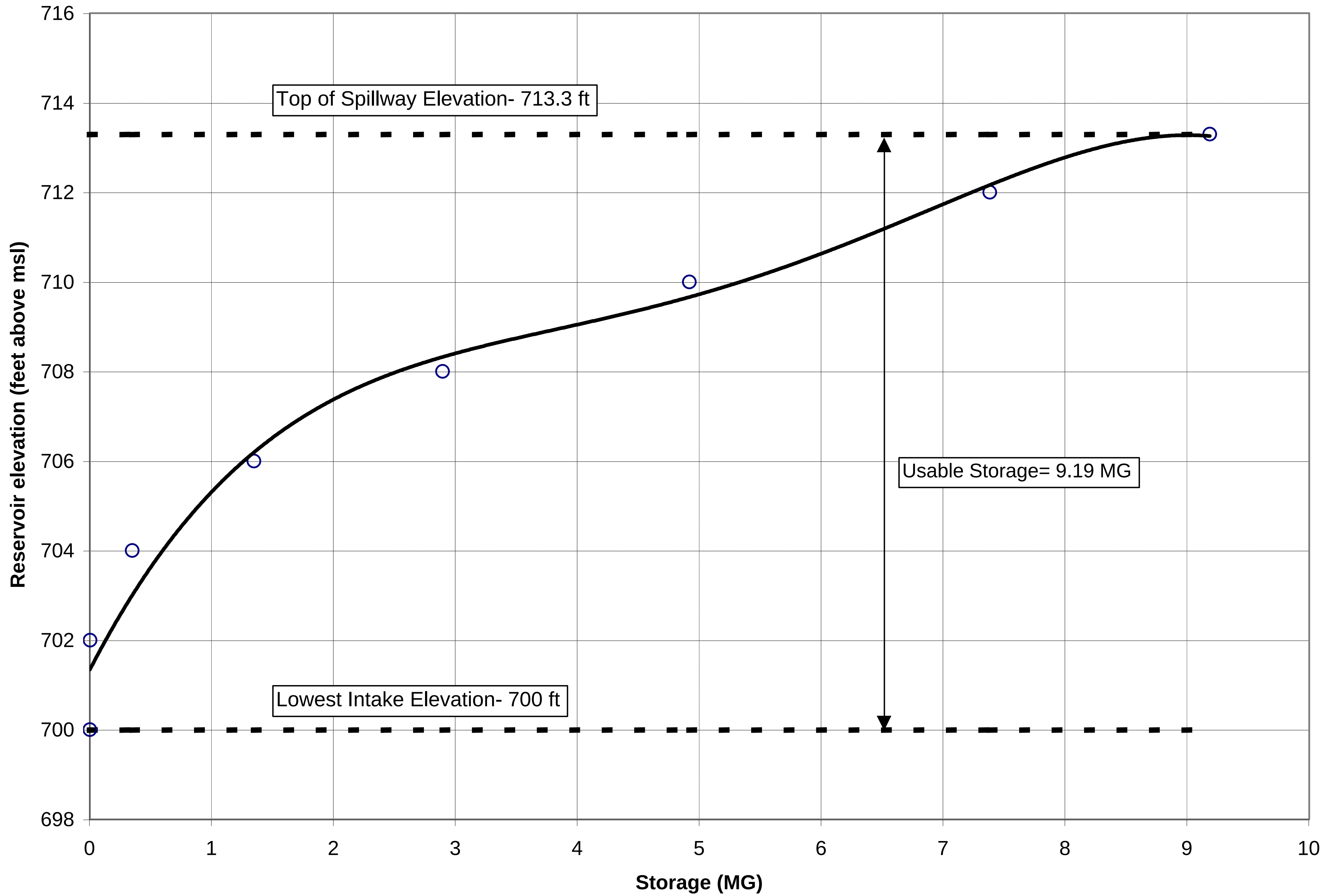


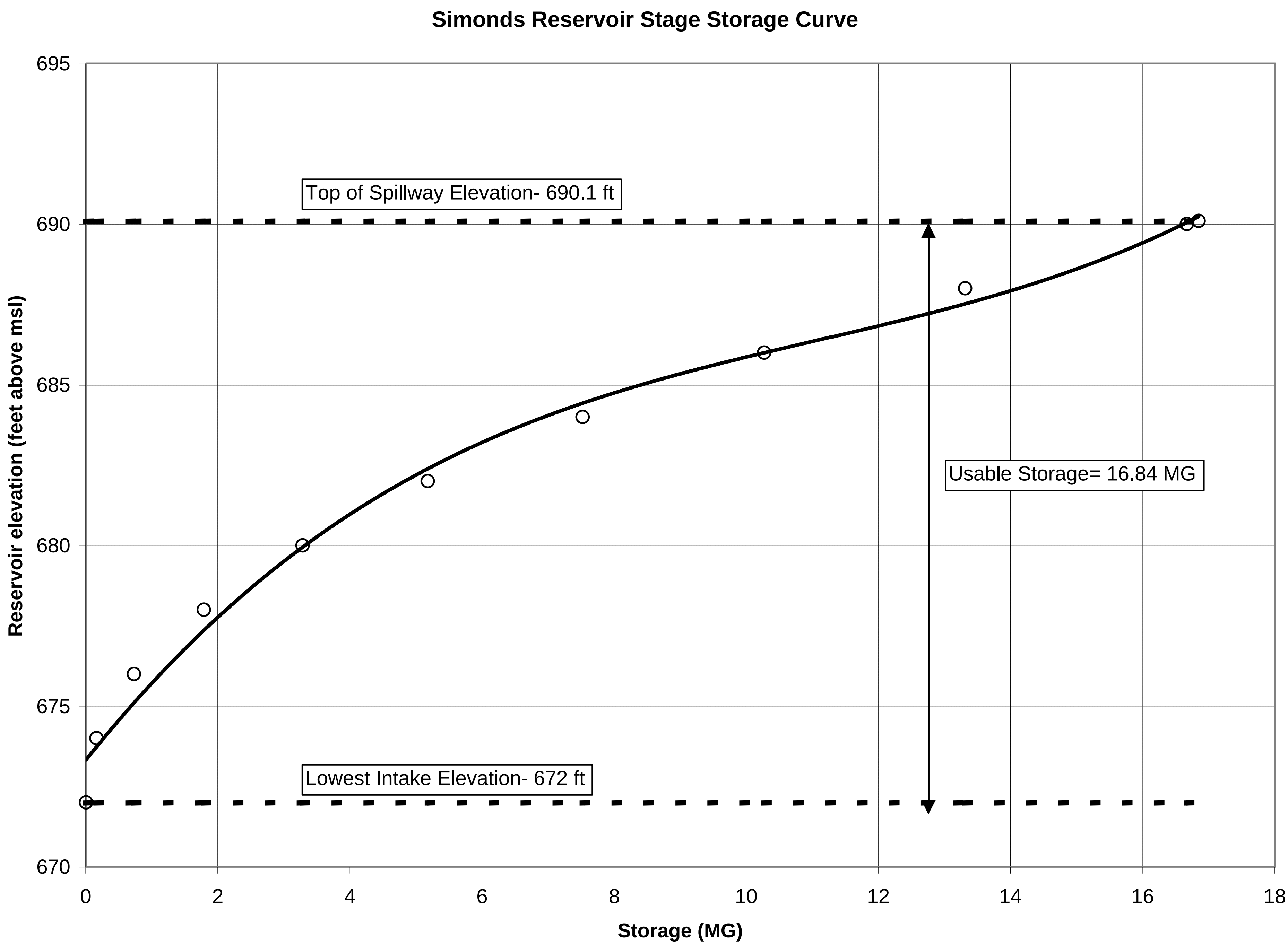
Wachusett Reservoir Stage Storage Curve
Top of Spillway Elevation- 892.4 ft
Lowest Intake Elevation- 882 ft
Usable Storage= 390 MG
Reservoir Elevation (feet above mean sea level)
Storage (MG)
895
890
885
880
875
870
865
860
0
100
200
300
400
500
600

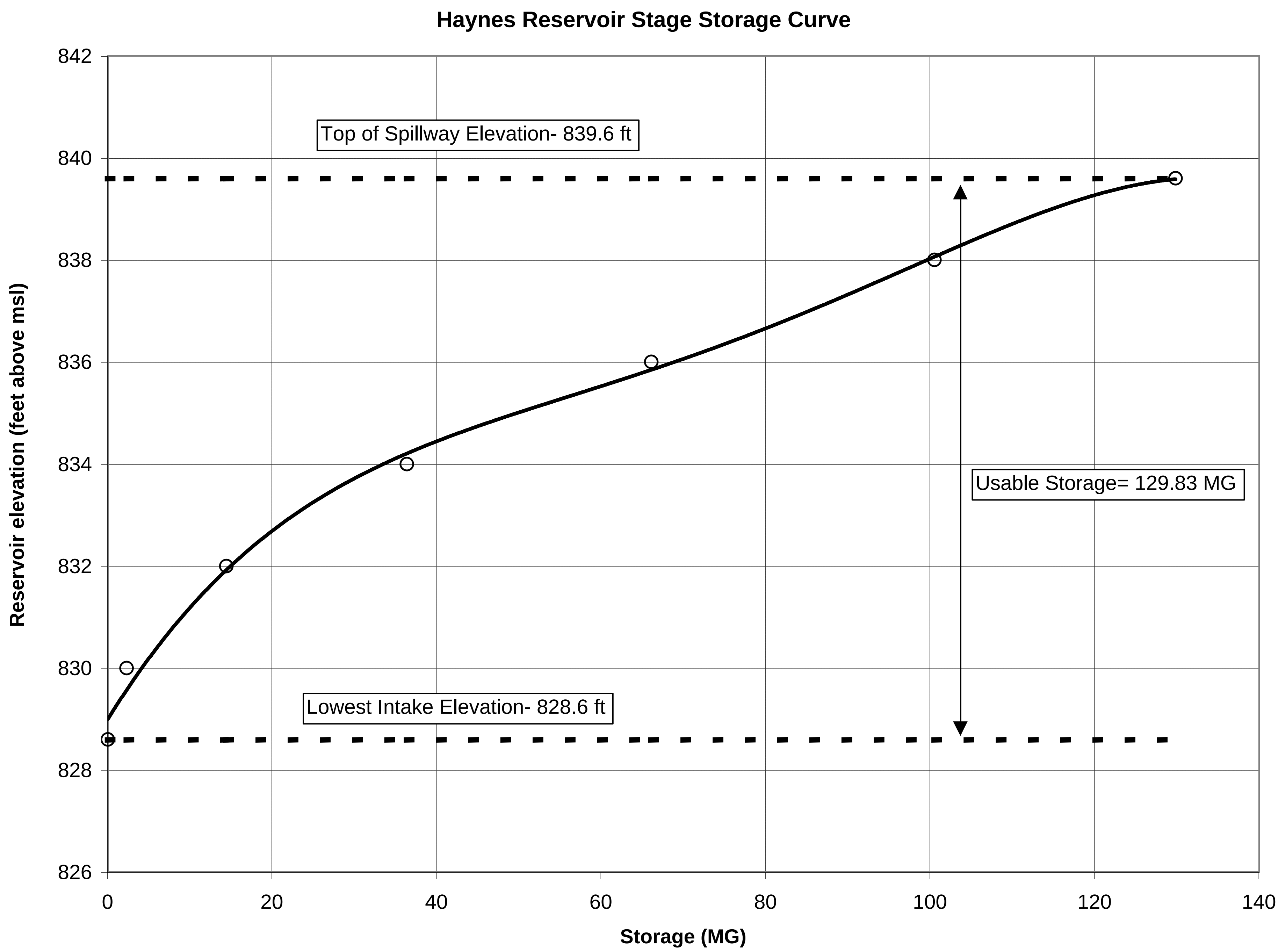


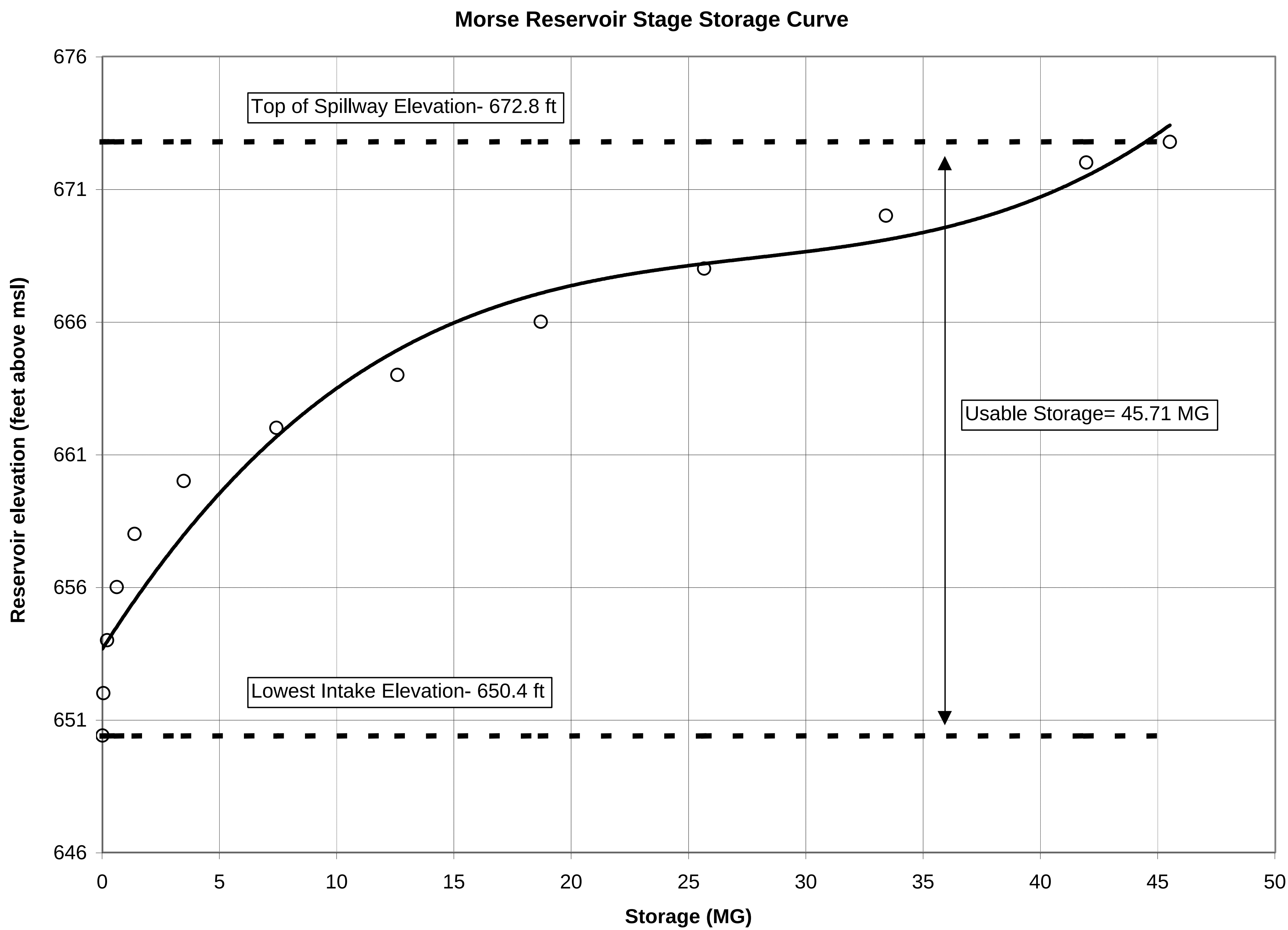
Notown Reservoir Stage Storage Curve
Top of Spillway Elevation- 733.8 ft
Usable Storage= 709.47 MG
Lowest Intake Elevation- 718.9 ft
Reservoir elevation (feet above msl)
736
734
732
730
728
726
724
722
720
718
0
100
200
300
400
500
600
700
800
Storage (MG)

Goodfellow Reservoir Stage Storage Curve

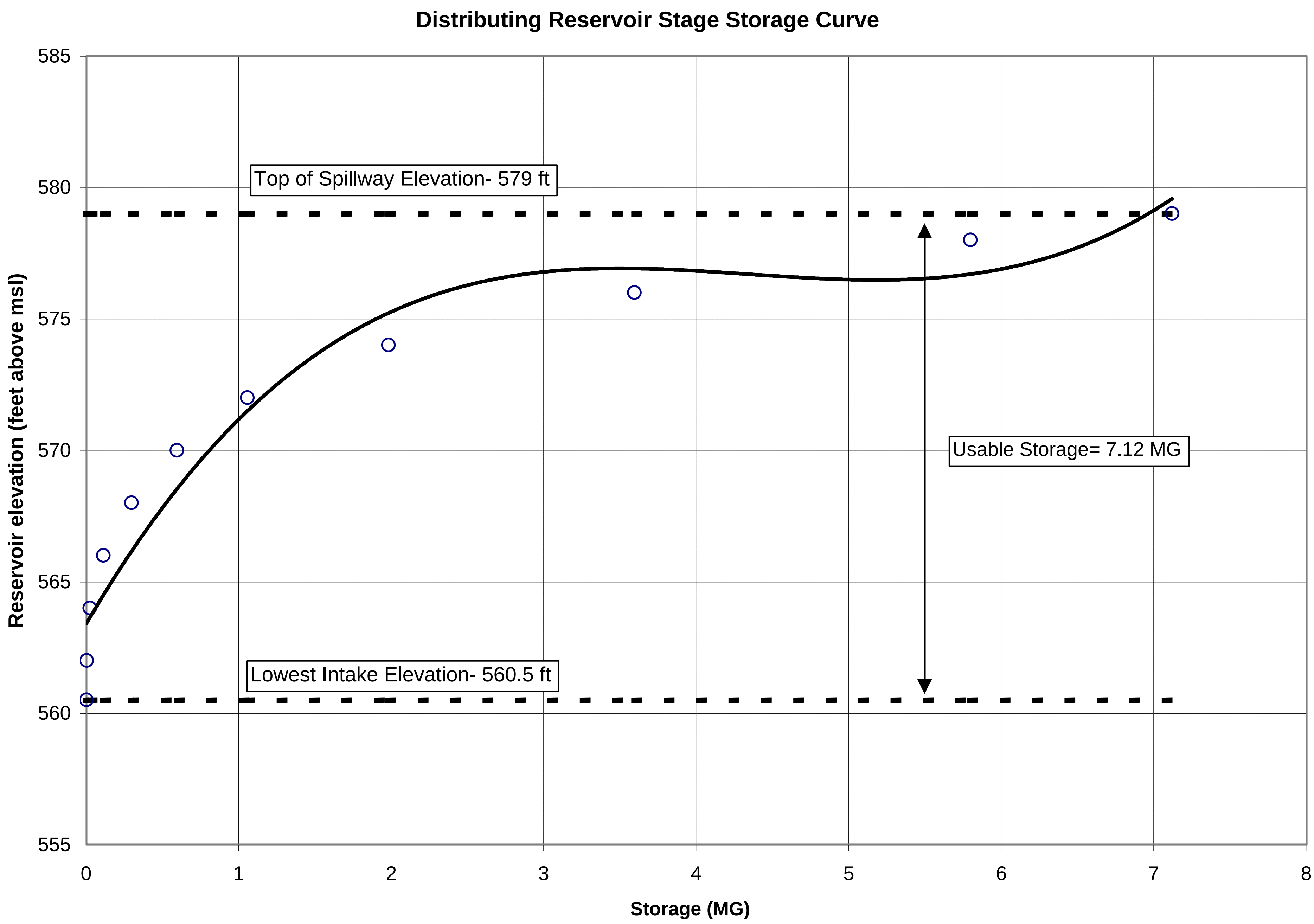



Simonds Reservoir Stage Storage Curve
Top of Spillway Elevation- 690.1 ft
Usable Storage= 16.84 MG
Lowest Intake Elevation- 672 ft
Reservoir elevation (feet above msl)
Storage (MG)
695
690
685
680
675
670
0
2
4
6
8
10
12
14
16
18


Haynes Reservoir Stage Storage Curve
Top of Spillway Elevation- 839.6 ft
Usable Storage= 129.83 MG
Lowest Intake Elevation- 828.6 ft
842
840
838
836
834
832
830
828
826
0
20
40
60
80
100
120
140
Reservoir elevation (feet above msl)
Storage (MG)



Morse Reservoir Stage Storage Curve
676
671
666
661
656
651
646
Reservoir elevation (feet above msl)
0
5
10
15
20
25
30
35
40
45
50
Storage (MG)
Top of Spillway Elevation- 672.8 ft
Usable Storage= 45.71 MG
Lowest Intake Elevation- 650.4 ft


Distributing Reservoir Stage Storage Curve
585
580
575
570
565
560
555
Reservoir elevation (feet above msl)
0
1
2
3
4
5
6
7
8
Storage (MG)
Top of Spillway Elevation- 579 ft
Lowest Intake Elevation- 560.5 ft
Usable Storage= 7.12 MG

Fall Reservoir Stage Storage Curve